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INFLUENCE OF ARCTIC OPERATIONS ON FUTURE SHIP DESIGN.*

By Captain R. B. Lank, Jr., U.S.C.G.

With the advent of modern efficient high-powered propelling plants and welded hull construction it is now possible to consider operation of especially constructed ships in the Arctic sea and other ice-infested cold ocean areas formerly denied the mariner.

The Arctic ocean may be described as being contained in a submerged bowl on top of the earth. The rim of the bowl consists of the continental masses of Eurasia and North America. In this bowl is a thick coating of ice that builds up in thickness and extent in the winter time and recedes from its boundaries in the summer, making it possible for ships to traverse its perimeter in relatively open water in the latter season. This ice cap has a rotary movement from east to west and during warm seasons of the year portions of the ice cap in the form of floes are carried through Denmark and Bering Straits. It is generally believed

* This paper received the award in the Society's Prize Essay Contest for 1946.

that seven feet of ice is formed in one year on the polar ice cap and that three years elapse before it drifts south. The thickness of the ice cap is far from uniform, as shifting winds and currents create tremendous forces within the ice cap which break the surface and pile the ice into masses to form pressure ridges, hummocks, and windrows of varying thicknesses and at irregular intervals. Such ice is then known as "Storis". Near the great land masses such as Greenland, great glaciers of ice flow to the sea to break off and become icebergs of such proportions that they must be avoided whenever and however met. For purposes of this article, navigation through Storis and sheet ice only is considered.

The attempts of whalers and explorers to penetrate the Arctic in the past are well known. Experience in the navigation of polar ice in modern times has demonstrated that vessels are afloat which can match the forces of nature and succeed in operating where former cockleshell vessels and their hardy crews succumbed. Icebreakers of the U. S. Coast Guard "*Northwind* Class", of which two are operated by the Coast Guard and three by the Russians, have successfully combatted the Arctic. In addition, two vessels of the same design have been built for the Navy, the *Edisto* and *Burton Island*. The *Northwind* negotiated Kennedy Channel and Hall Basin as far as 81° 44′ North Latitude, just off Cape Murchison, Ellesmere Island in August, 1946, and the *Edisto* penetrated to 75 degrees N. Lat. east of Greenland in October, 1944. The *Northwind* is presently acting as the spearhead, breaking a path through South Polar ice fields of considerable size and thickness for the central group of the Byrd Antarctic Expedition.

The first icebreaker built to the Coast Guard account was turned over to the Russians in 1943 and renamed the *Severny Veter*. This vessel operated successfully in the Sea of Okhotsk during the spring of 1943 and then proceeded via the Northeast Passage to the White Sea, where it has since operated. No direct reports have been made on its operations there, but it must have been favorable, as the Russians requested two more of the same type in 1944. The *Westwind*, renamed the *Severny Polus*, and the *Southwind*, the *Admiral Makaroff*, were transferred to the Russians in the fall of 1944 under terms of the Lend-Lease Act. The Russians recently announced that the *Severny Polus*

was making an expedition from west to east at high latitudes north of the New Siberian Islands. This evidence would indicate that the ships perform well during at least the warmest seasons in the Arctic. Winter operation in the Arctic, except where the Gulf Stream laps around the northern tip of Norway to Murmansk, with modern ships is unknown; aside from the Russian icebreaker *Sedov* 1937-40 venture, when the ship was frozen in the ice cap and eventually was released by the *Joseph Stalin* northwest of Spitzbergen at about 80° N. Latitude. The exact facts of this episode were unreported.

The fundamentals involved in the design of vessels to combat Arctic ice fields are well delineated in the recent paper, "Development of Ice-Breaking Vessels for the U. S. Coast Guard", by Rear Admiral Harvey F. Johnson, U.S.C.G., read before the Society of Naval Architects and Marine Engineers in 1946, and the principles propounded therein are hereafter generally extended to cover the subject matter.

Types of Ships.

For purposes of this article, ships traversing the Arctic are divided into two classes—those which can break or work ice and make their way unassisted in any floating ice except glacial, and those unable to cope with ice. The first class includes such types as icebreakers and combat ships of the cruiser or aircraft carrier type. The second category would include the auxiliary vessel and the dry and tanker type of cargo ship.

The Icebreaker.

The icebreaker must be heavily powered with installed shaft horsepower of at least two to three or more times the displacement. The length of a ship which proceeds alone should be the smallest practicable to take advantage of maneuverability inherent in a short length, and thus be able to follow tortuous leads in ice fields. However, if the ice-breaker is to convoy ships of less power and strength, a length and beam greater than that of the convoyed ships is desirable; the greater length to insure that the lane broken in the ice has no greater radius of curvature than the following ship or ships can negotiate; the greater beam, of course, to insure width of lane or channel. The draft should only be limited by consideration of channels in home or foreign

ports and bars to be negotiated; the deeper the propeller tips are below the surface the less the chance of damage.

The hull underwater body should be ovate, that is, like half an egg-shell, with no flat surfaces presented to the ice, with the slope of the ship sides about twenty degrees. The bow buttock slopes should be very gentle and should be refined as necessary by thickness of the maximum ice to be encountered. The hull must be essentially double-ended to be effective in a sternward as well as forward motion, with as much protection as possible given the rudder and other hull appendages.

The hull should be sufficiently strong so that when ice fields of limitless extent beset the vessel, it will be lifted out on the ice and not be crushed by the unlimited forces encountered. This weight of the ship to be lifted is known, making calculation of forces and structure to withstand same a matter of usual mathematics. The shell plating and framing in the bow and water line regions require additional strength to allow for impact reactions.

The main propelling plant must of necessity be capable of producing large powers economically and flexibly. Electric drive, with its ease of control, is a *must* to prevent damaging impact of propeller blades on ice masses. Economy of operation is necessary to obtain great crusing radius, because not only are distances great between fueling stations, but also there is always a possibility that the ship may be frozen in and immobilized for long periods of time. Multiple screws will be required on an Arctic icebreaker to obtain thrust of great magnitude. In Arctic ice that is of thickness greater than the draft of the ship, bow propellers may be vulnerable, and such a practice is not ordinarily recommended. The projected Canadian icebreaker, however, has two bow wheels, and only experience will justify their fitting, although it is quite probable that good icebreaking qualities and maneuverability are obtained thereby. Propellers should be designed to obtain maximum thrust at zero speed of advance and have extremely heavy sections.

The Auxiliary Type.

Vessels for work in the Arctic must contain such strengthening as required by classification societies, and in addition other factors should be considered, even though such vessels are escorted by icebreakers. Ice fields are rarely stationary and,

even though a channel is cleared by the icebreaker, the force of winds and currents on the ice field may close the channel immediately astern of the icebreaker. Under such circumstances the ice friction developed along the vertical sides of the usual cargo vessel will act to retard or stop forward motion until freed by return runs of the ice-breaker or shift of wind and current.

Future auxiliary ships should be designed to take such an occurrence into consideration, by shaping the hull so that no flat surfaces are presented to the ice. A commercial type, known as the Isherwood Arc Form, is in existence, which will give the approximate cross sectional shape required and, by dispensing with usual parallel middle body in favor of curved waterlines, superior shape to force ice leads will result. Ships with a parallel body fit so snugly in a broken ice channel that changes in direction are often difficult, if not impossible, to make. Shape in the waterline will aid in steering the vessel, as a change of several degrees in the ship's heading can readily be obtained, even though the sides of the channel are parallel and the channel width equal to the beam of the ship.

A great portion of ice broken by an icebreaker goes down under the hull and reappears on the surface astern. This ice in turn must pass under or around the convoyed ships. Such action is facilitated if a cut-away bow is worked on the convoyed vessel, as lines of flow along diagonals will be much less acute. In a narrow or narrowing channel with normal bluff bows, ice may stay on the surface and work aft to create a wedging action. In addition, a sloping forefoot will aid an auxiliary vessel to break ice unassisted up to a thickness dependent on its installed shaft horsepower.

To be certain that an auxiliary will not be crushed between shifting ice fields, the plating and framing should be of sufficient strength so that the vessel will be lifted clear of irresistible forces. With well-shaped underwater bodies, the forces imposed are not of great magnitude and can be provided for with little increase in overall weight.

The Coast Guard tenders of the *Storis* and *Cactus* Classes are cargo vessels designed with these principles in mind, and have been successful both as cargo carriers and icebreakers in northern latitudes.

Design Factors Common to Both Types.

Propellers should be of heavy cast steel type, and designed so that maximum thrust is obtained at zero speed of advance.

Special attention should be given all underwater body appendages to insure rugged durable details. Bilge keels of the ordinary type are very vulnerable and may be easily severed from the ship's hull by the broken ice coming under the bottom. To have such bilge keels curl up like the top of a sardine can is quite common. Double plate V-shaped bilge keels have been successful on smaller Coast Guard cutters. On large vessels, for structural reasons, bilge keels should not be fitted.

Electric drive, with its ease of control, is indicated for all vessels working in ice. With pilot house control, it is possible to control a propeller to prevent striking large ice bodies, minimizing propeller and shafting damage.

Ships with ordinary sea chests or scoop inlets for circulating water will experience situations when ice will plug up the inlets, stopping all machinery until cleared. By injecting the discharge back into a special design of sea chest, it is possible to keep the suction clear of ice and obtain any desired temperature of cooling water. In addition, a recirculating sea chest provides a ready source of warm water which can be connected to the fire main to combat icing conditions on topside.

Future ships for Arctic service must have provisions made for the comforts of the crew. Insulation, ventilation and heating of quarters and machinery spaces require consideration of the low atmospheric temperatures that may be encountered.

Of great importance when considering the low temperatures involved is the quality of material that is to make up the hull and deck erections. Low temperature coupled with shock loadings enhances the probability of cleavage fracture in steel many hundreds of times over that which might occur in tropical climate. It therefore behooves the designer and shipbuilder to use great caution in avoiding discontinuities and notches in the structure and welding. In addition, all steel subjected to low atmospheric and water temperatures should be tested for notch-sensitivity to insure trouble-free operation.

When considering future ships, thought must be given to an atomic power plant. They should make the ideal power plant for icebreakers and ships in Arctic service. Weight and space

presently devoted to fuel can then be utilized for additional power and hull strength to create the "irresistible force" to overcome the "immovable body" of the frozen polar ice fields.

If full knowledge of the physical properties of ice existed, it is possible that a more rational approach could be made to the subject matter. Little data have been published on the tensile, compressive and shearing strength of salt and fresh water ice as existing under natural conditions. These properties could be determined (It does not seem like such a big job as compared with other research projects presently underway) and thus open the way to analyze ice-breaking in a scientific manner to end the challenge of the Arctic and Antarctic.

SUMMARY.

From the foregoing, it can be seen that Arctic operation of ships influences practically all phases of ship design. Hulls will be shaped and strengthened to break ice, resist its forces of compression and impact. Bow, stern and midship bodies must be specially shaped. The size of power plant will be determined by the thickness of ice encountered rather than the requirement of speed in open water. Material of hull, character of propeller, circulating water and hotel accommodations for crew all require special attention. The *Northwind Class* icebreaker has demonstrated that Arctic ice can be conquered under certain conditions. It now appears entirely possible that the future will see a further development of this type which will be capable of conquering the Arctic seas under any and all conditions.

A STUDY OF THE CAUSE OF HARD SLAG DEPOSITS ON FIRESIDES OF NAVAL BOILERS.

By Commander L. C. McCloskey, U. S. N. R.

Statement of Problem.

Early in the war, a new and severe boiler casualty began to appear. Slag deposits formed on the firesides of superheating tubes:—heavy enough to completely plug gas lanes, over much of the superheater; and hard enough to resist all efforts to remove them. The condition has since appeared to some degree in nearly all classes of ships operated by the Navy; with deposits on both horizontal and vertical tubes, as well as on both superheating and generating tubes.

Location and Appearance of Deposits.

Furnace exits for all Naval boilers are composed of a screen of two, three or sometimes four rows of larger diameter tubes, set on wider spacing than those following. These screen tubes are immune, slag forms only on the tubes immediately following. Figures 1, 2, 3, 4, and 5 are photographs from an ACV, a CVL, a CL, an LSD, and a DD. They are all views of conditions on the front of tubes that immediately follow the screen. Figure 4 shows the generating tubes of a saturated boiler; while the others all show the tubes of superheaters.

Inability to Cope with Growth of Deposits.

Soot blowers, strategically located have been the time-tested means for protection against growth of deposits. The new type of deposits formed in areas hitherto immune. Because of this, and the fact that such areas were subject to higher gas temperatures than commercially available alloys could stand; no protection had been planned for. That for adjacent areas was wholly inadequate to carry over and had no effect. The nearest, on standard boilers, is situated just below the superheater, in back of a stud-tube shadow baffle. Falling debris from the superheater tubes frequently buried the soot blower element in a mass of

fused debris, as though buried in concrete. It could not even protect itself, let alone protect superheater tubes. War time practice of having all boilers in service always, when at sea, and of ships remaining at sea for maximum periods, prevented the laborious hand work which probably could have kept slag deposits under control.

Serious Aspects of Deposits.

Gas flow areas are reduced by slag deposits, and only reduced amounts of oil can be burned by the same air horsepower input. Boiler capacity and ship speed are thus reduced.

Heat absorbing surfaces are fouled by slag deposits, and boiler efficiency reduced. Cruising radius is thus reduced.

Protective radiant cooling for boiler structural members, is diminished when the cool boiler tube surfaces are covered with hot-surfaced slag deposits. Many superheater tube supports burned, requiring complete superheater tube renewal to repair them.

Gas flow areas plugged by slag deposits caused excessive gas velocities, through areas remaining open. They also caused by-passing through partially closed off end and top seals. This resulted in "torching" which often caused burning out of;—tubes, baffles, and casing panels. Figure 6 illustrates a burned casing panel.

Chemical Nature of Deposits.

Innumerable analyses of slag samples indicate them to be heterogenous: a mixture composed of one half to two thirds, either of sodium sulphate or of a mixture of sodium sulphate and vanadium pentoxide; plus lesser amounts of the oxides of calcium, magnesium, silicon, iron, and aluminum; plus very small amounts of many other oxides. Vanadium is found only with fuels that have come from certain fields. No chlorides, carbon, or carbonates are commonly found. Slags lack uniformity. Different samples from the same boiler often differing as much as if from different boilers. Analyses for the same constituent at sections a quarter inch apart in one lump showed 54% in one, and 21% in the other.

Physical Nature of Deposits.

The physical nature of deposits varies considerably; from a chalky matrix filled with vitreous nodules, to a vitreous matrix filled with chalky nodules. It appears that basically, slag is much like a very fine grained and dense chalk which undergoes varying degrees of fusion for some, but not all, components; a fusion that takes place only after deposition. The chalky part is soft enough to be scrubbed apart by hand. The vitreous part is often hard enough to cut glass. Figure 7 illustrates the high content of crystalline, or vitreous, character in very hard slags. Figure 8 illustrates the low content in softer slags.

Fuel Design Characteristics.

Fuel oil today is a more or less waste by-product from refineries making many other saleable products out of crude oil. But it is a product with certain sales value, and for this reason subject, within a fair degree, to buyers specifications. Fuel oil is basically the remaining dross after all lighter components have been distilled off from crude oil and the rest sent through a second process which causes chemical changes to produce still more distillate, leaving a practically non-distillable residue, which has been cooked to 750°F or more. The very maximum of distillation products have been removed from it. It has been effectively cleaned of contaminating matter during processing; but remains a very viscous tar, with a high ignition temperature, and a minimum of vapor forming properties. It is far too thick and viscous to be transported or burned as a fluid. Some of the less valuable distillate previously removed is therefore used to put the tar into solution, carefully blended to produce the desired viscosity. Fuel oil then, is a non-distillable tar held in solution by a light distillate. Just as heating separated the distillate originally, so will any further heating;—only a bit more easily. Navy fuel is held to a maximum of 0.1% of ash, but averages only about half to three quarters of that. It is also held within 15 and 25 SSF at 122°F., averaging about 21 to 23. Moisture is negligible. There is roughly 11% hydrogen and 1½% sulphur in it, much of the hydrogen coming from the solvent.

For several reasons, fuel oil is subject to seawater contamination during all the time that it is aboard ship, including time

aboard the tanker as well as on the consuming ship. No accurate figure is determinable for the amount of sea water contamination as-fired. Many ships, through considerable effort, may hold it to 1 or 2%; but for many others, probably most others during war time, the figure is indeterminate and considerably higher. Sea water adds chlorides, carbonates, sulphates, and silicates, plus a host of lesser contaminants. The chlorides and carbonates react in the furnace with sulphur in fuel to form sodium sulphate.

Fuel oil as-fired is therefore, a high ignition, high viscosity, non-distillable and sulphur bearing tar; held in solution by a thin petroleum distillate; and contaminated to unknown degree by sea water. It was originaly blended to be atomized at 150 SSU, which viscosity should result when heated to within two or three degrees of 135°F.

Boiler Design Characteristics.

There are many different designs of boilers used by the Navy, but one of them is in great preponderance for combat ships;—The superheat-control boiler. It alone will be considered here, in the interests of brevity. It has two separate furnaces, but only one uptake. Oil burned in one furnace is used to superheat the steam made by oil burned in the other furnace. Gases from the former are sent through a superheater, which is protected from the intense furnace radiation by a small and loose screen of generating tubes, and discharged into the saturated side furnace. All gas is sent through the generating tubes of the saturated side and then through an economizer to the uptake. Saturation temperature will be close to 500°F. Superheated steam temperature should be close to 840°F. When operating properly, very nearly the same amount of oil is burned in both furnaces.

Superheaters are most frequently built of one inch tubes on 1½ inch pitch. They are in staggered rows, 1-5/16" apart. Four hairpin loops are nested horizontally, so that gas goes through three vertical rows of screen tubes, and then through eight horizontal rows of superheater tubes before entering the saturated furnace to merge with the gases there.

The size and output of boilers of different ships will vary. Dimensions are scaled accordingly, but the same relationships hold quite constant.

All sizes are designed for a satisfactory performance between 10 and 120% of designed full power. The 10% value is ordinarily that load required for peace time cruising speed on one boiler. War time cruising speeds are higher, taking about double this load, and all boilers are kept on the line. A four boiler ship then, normally operates with boilers at 10% of rating in peace time, but ony 5% of rating in war time.

Furnace Design Characteristics.

Naval furnaces are designed for considerably higher maximum heat release than is ever found in merchant practice. All can burn satisfactorily as much as 2½ gallons per cubic foot of furnace volume per hour; at which time the furnace temperature will be 3000-3050°F. Furnace temperature is a function of release rate, decreasing as the load decreases. When values approach 1800°, combustion becomes poor, causing instability of ignition. It can be assumed then, that the temperature range for Naval furnaces will be 1800-3000°F. for loading rates between 10 and 120% of full power. The fact that nearly all war time operation is at loads below, or closely bordering those at which ignition is unstable is probably a contributary cause to slagging conditions.

Burner Design Characteristics.

In general, there are two burner registers used for combat vessels, one with a top capacity of about 1200 pounds of oil per hour, the other with about 2100. The performance of both is similar, the ability to produce an average of 13.5 to 14.0% CO_2 at all loads between 10 and 120% of full boiler power. The 1200 and 2100 pound loads can be increased somewhat for different ship requirements.

Atomizers consist of sprayer plate and nozzle, both of which have several minor variations.

Sprayer plates for steaming loads are all made from a common blank; which has the same size whirl chamber, has its outer face dished, and has the outer edge of its orifice rounded. The orifice diameter is varied for capacity. The tangential slots have a total cross section area, determined both by size of orifice and angle

of spray desired. It is customary to cut four slots on small plates and six on large plates.

There is but one design of nozzle used, the "semi-wide range". It displaced the "standard" nozzle, from which it is a direct copy in all but one dimension, just as the recent war came on. The dimension difference is in diameter of the nozzle boss. That on the "semi-wide" nozzle is 5/16" while on the "standard" it is ½". Much controversy exists as to whether this change has proven beneficial or harmful. Its effect is to shorten the length of the resistors (the closed portion of the tangential slots) to about 13% of their original value. Conversion from static to velocity head is accomplished in these resistors. The decreased resistor length reduces its friction, which results in a slightly higher capacity for the "semi-wide" than for the "standard". Its altered dimension does not affect the hydraulic principles involved in width of range, however, as is easily seen by comparison of published capacity curves. The same change in atomizing pressure produces the same percentage change in capacity. The nozzle is, very unfortunately, mis-named. Arbitrary assumption, that the reduced resistor friction would permit lower atomization pressures led to early sanction of 75 to 300 pounds as the range for "semi-wide" nozzles, while that for the "standard" remained unchanged at 200 to 300 pounds. That this assumption was incorrect has been recognized, and the lower limit of atomizing pressures has gradually been raised. Many reports of poor atomization led to an increase in the allowable minimum pressure. Several other possible causes are also co-incidental, but it must be recognized that hard slag has been found only during the period when these adverse reports of poor atomization by the "semi-wide range" nozzle were being received.

Theoretical Considerations Concerning Atomization.

Oil is atomized, or converted from bulk to small droplets in order to increase its ratio of surface-to-mass. Liquid oil can not burn, but as a vapor it can. Change in state requires absorption of heat. Thus, a time element becomes involved. Rate, or time of heat absorption increases directly with the ratio of surface-to-mass. For every time that particle diameter can be reduced to half, the time of burning will also be reduced to half. And

conversely, particles twice as large will take twice as long to burn. Good atomization produces droplets which probably average about 4/1000ths of an inch in diameter.

Atomization is accomplished by conversion of static head to velocity head in the sprayer plate. A slow moving stream of bulk oil under high pressure, is made to flow through several resistors in parallel. These convert all static head into velocity head, and discharge their high velocity streams radially against a curved deflecting surface. This surface is shaped so that the streams merge to form a hollow parabolic stream having helical flow, which, on release from confinement, emerges as a conical stream. The constantly increasing diameter of the cone thins the walls to eventual disintegration into very small droplets. The necessary energy to tear bulk oil apart into small droplets comes from the pump horsepower input, as pressure, which is converted by $h = \frac{mv^2}{2}$ into high velocity. Quality of atomization is therefor proportional to atomizing pressure.

The resistors for conversion of static to velocity head are the closed portions of the tangential slots. They serve two other important functions, that of governing the quantity of flow, and that of direction of flow to the whirl chamber.

The whirl chamber functions best when velocity of the streams delivered to it are approximately 4000 ft. per minute or higher. At this value, the whirl is rapid enough to take on a hollow character, with the walls thinning sharply at the orifice outlet. It is essential for good performance that the parabolic stream have this hollow character. Leakage past the resistors weakens the velocity of their delivery, as well as introducing oil in a direction which tends to destroy the hollow character of the parabolic stream. The dimensions of the whirl chamber are fixed. Then, enlargement of orifice for higher capacity results in a thicker stream on delivery to the orifice, with resulting coarser particle size. Also; enlargement of the tangential slots for higher capacity results in a delivery decreasingly tangential and increasingly sideways, which weakens the hollow character of whirl.

The sprayer plate is designed and tested for oil having a very definite ease-of-flow, a viscosity of 150 SSU. An increase in viscosity thickens up the whirl chamber stream and increases capacity at the expense of coarsened particle size. A decreased

viscosity thins the whirl chamber stream to decrease capacity. But;—since decreased viscosity is the result of overheating regular fuel oils, it results in coarsened particle size because of a generally neglected reason. Overheating causes a flashing to vapor, of the thin "cutting stock" component of residual fuels, on the loss of static pressure at exit from the resistors. The back pressure of a vapor-plugged whirl chamber causes intermittency of flow. The intermittency being the cause alike, of furnace carbon deposits, and of tendency to cause furnace pulsation.

It is a practical impossibility to measure particle size at atomization, except in a relative way. Particle size must be small enough to satisfy the time element invoved with passage of the particle from atomizer to furnace exit, so that combustion will have been completed within the furnace. There are many factors involved in the time of passage from atomizer to furnace exit. One of the most important of these is the velocity of gas through the furnace. At the designed load of 10% of full power, an oil particle will be in the furnace 12 times as long as at the overload of 120% of full power. There is a tendency to use an increasingly higher excess air as load is decreased, which pushes the oil faster to the exit than design calls for. Another important factor is furnace temperature. Increasing load gives higher furnace temperatures and faster combustion. But the temperature at maximum load burns oil only 6 times faster than at minimum load;—while it pushes it out 12 times faster. Still another factor is the throttling of air registers. It is the aim of the burner designer to produce a cylindrical stream of air having uniform velocity over its cross section, and to cut across this with a conical stream of oil. To throttle, or partially close, air registers results in high outer velocities of the air cylinder, and low center velocities. The local high velocities pick up the oil particles and carry them faster to the exit than does a stream of balanced velocities. The use of fewer and larger fires, rather than more and smaller fires, give the same effect as the throttling of registers. Split plate firing, (different sizes of sprayer plates in use in the furnace at the same time), also gives the same effect as throttling of registers.

There are a great many factors involved in the problem of atomization. The designer, the instructor, and the operator; all have a share in the result.

Theoretical Considerations Concerning Behavior of Small Particles in Gas Streams.

'It has been indicated that average particle size of well atomized oil is probably about 4/1000ths of an inch in diameter. Such a figure is very controversial, depending on how it was arrived at. Since most values of atomization are relative only, the above is safe as an assumption.

Navy oil averages about 0.07% ash, as-made. Then the size of ash remains (if molten) from a droplet of atomized oil would be about 2 millionths of an inch in diameter. There are very good reasons for assuming that the remains of oil droplets burned completely in the furnace are at least half molten, and carrying the unmolten components in slush-like form.

Particles of fly ash from furnace burned oil have a size that is of a second order of magnitude. As such, surface-to-mass would be infinity, and inertia would be zero. They would have gas-like properties, in that they could be air-borne perfectly, and could not be thrown out of a deflected stream. They would be the opposite of gas as for their radiating qualities. Infinity ratio of surface-to-mass would cause them to radiate their heat to approaching boiler surfaces and drop in temperature so fast as to become considerably colder than their gas vehicle. It is to be expected then, that fly-ash from oil fog burned in the furnace can never build slag deposits in a boiler, and will be much colder than the gas which carries them.

Particles of fly-ash from oil, not furnace burned, but burned in air-borne status, may not be as small as particles from furnace burned oil. Radiation of heat during combustion might be sufficient, to prevent any of the components from melting. In this case, there would be skeletal remains with overall dimensions approaching that of the original drop. Surface-to-mass would be even greater than for molten particles. It is to be expected then, that fly-ash from atomized oil burned in the tube bank can never build deposits in a boiler, and will be much colder than the gas which carries them.

Particles of unburned, or incompletely burned, oil that has been atomized have a size whose magnitude is of first order. These will radiate slower than fly-ash, as well as to be thrown out of deflected gas streams. If wet and tar-like they will spatter and

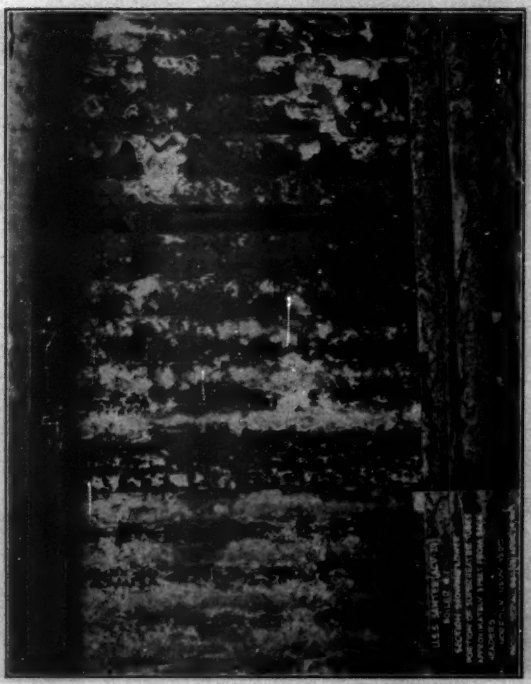

FIGURE 1.—SLAG FORMATION ON FRONT OF SUPERHEATER ON AN ACV. SCREEN TUBES HAVE BEEN REMOVED.

FIGURE 2.—SLAG FORMATION ON FRONT OF SUPERHEATER ON A CVL. SCREEN TUBES HAVE BEEN REMOVED.

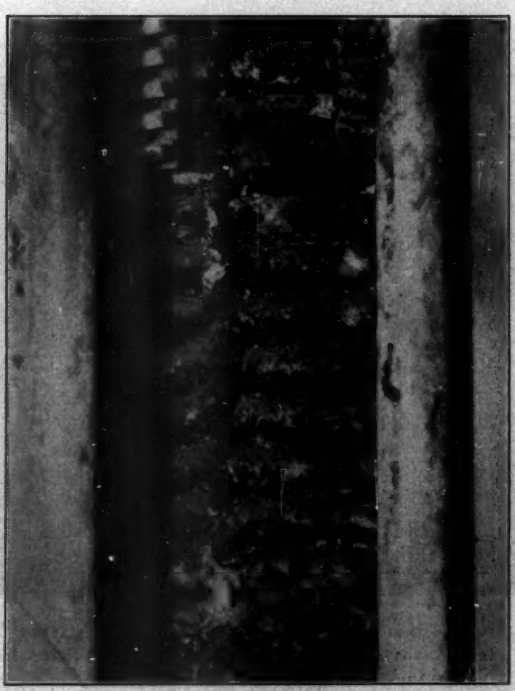

FIGURE 3.—SLAG FORMATION ON FRONT OF SUPERHEATER ON A CL. SCREEN TUBES HAVE BEEN REMOVED.

FIGURE 4.—SLAG FORMATION ON FRONT OF GENERATING TUBES IN A SATURATED BOILER ON AN LSD. SCREEN TUBES HAVE BEEN REMOVED.

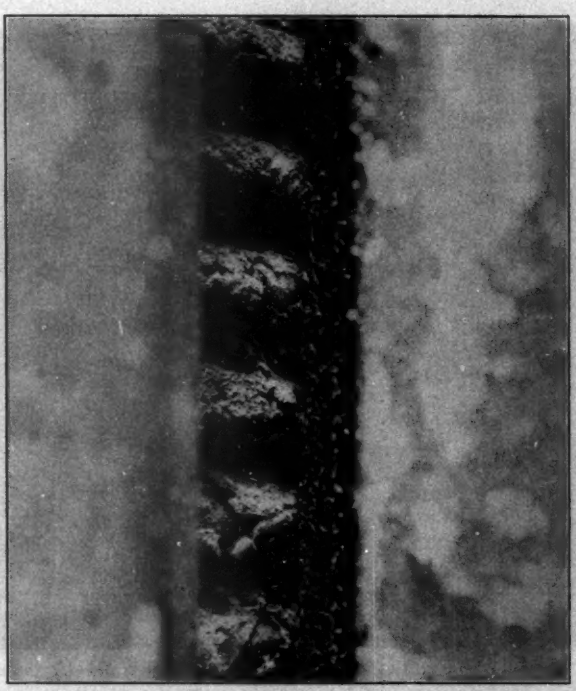

FIGURE 5.—SLAG FORMATION ON FRONT OF SUPERHEATER ON A DD. SCREEN TUBES HAVE NOT BEEN REMOVED.

FIGURE 6.—CASING PANEL BURNED BY "TORCHING" OF GAS BY-PASSING UNDERNEATH A PLUGGED SUPERHEATER.

FIGURE 7.—HIGH CRYSTALLINE, OR VITREOUS, CONTENT OF VERY HARD SLAG FROM A CVL.

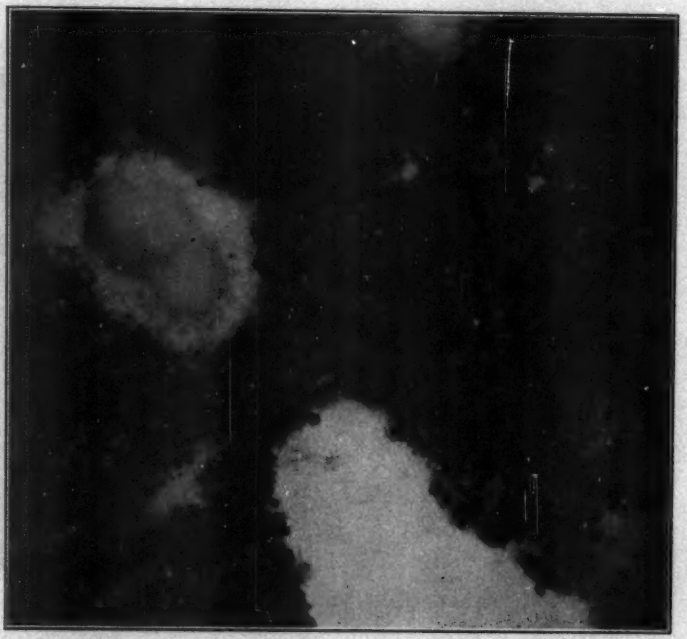

FIGURE 8.—LOW CRYSTALLINE, OR VITREOUS, CONTENT OF SOFT SLAG FROM AN AKA.

FIGURE 9.—VIEW, THROUGH SCREEN TUBES, OF A SUPERHEATER RECENTLY CLEANED BY WATER WASHING.

FIGURE 10.—VIEW OF UNDER SIDE OF FIRST FOUR ROWS OF SUPERHEATER TUBES, OF SUPERHEATER SHOWN IN FIGURE 9.

FIGURE 11.—VIEW OF REAR OF FOURTH ROW OF TUBES, OF SUPERHEATER SHOWN IN FIGURE 9.

FIGURE 12.—CLOSE-UP VIEW OF CONDITIONS SHOWN IN FIGURE 11.

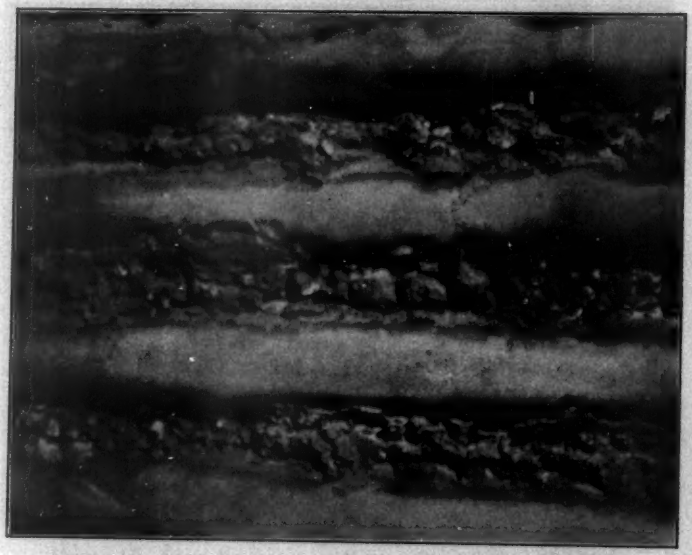

FIGURE 13.—CLOSE-UP VIEW OF CONDITIONS SHOWN IN FIGURE 11.

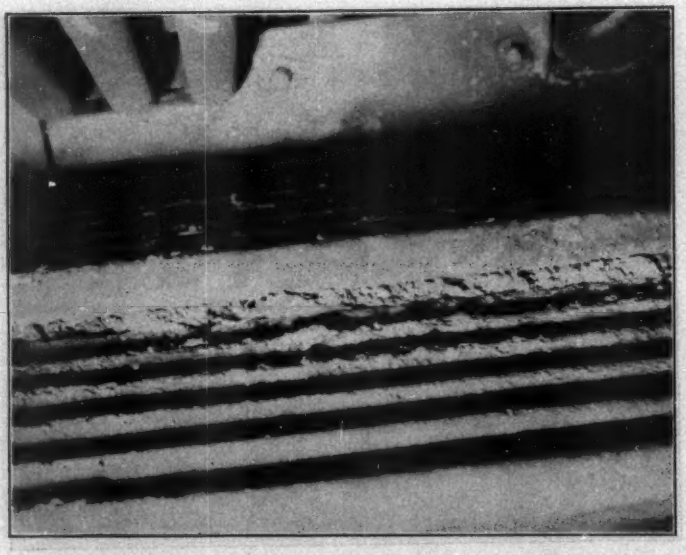

FIGURE 14.—VIEW OF SLAG BETWEEN FIFTH AND SIXTH ROWS OF SUPERHEATER SHOWN IN FIGURE 9.

FIGURE 15.—VIEW ILLUSTRATING NUCLEI CHARACTER OF PLUGGING. THE INITIAL OBSTACLE FORMED BETWEEN THE THIRD AND FOURTH ROWS, BROADENED, THEN SPREAD TO INCLUDE THE GAP AHEAD.

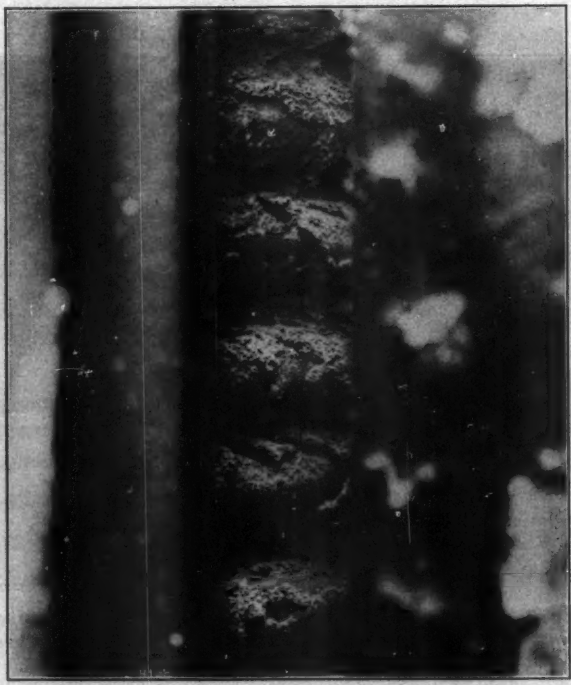

FIGURE 16.—THICKENED SLAG COATING WHICH HAS CRACKED LOOSE, HEATED UP, SOFTENED, AND SLIPPED.

FIGURE 17.—THICKENED SLAG COATING ON VERTICAL TUBES WHICH HAS HEATED UP AND RUN.

FIGURE 18.—REFER TO FIGURE 11. CLOTS TOO HEAVY TO SPAN THE GAP OF THE INNER LOOPS HAVE DROPPED OUT OF THE GAS STREAM.

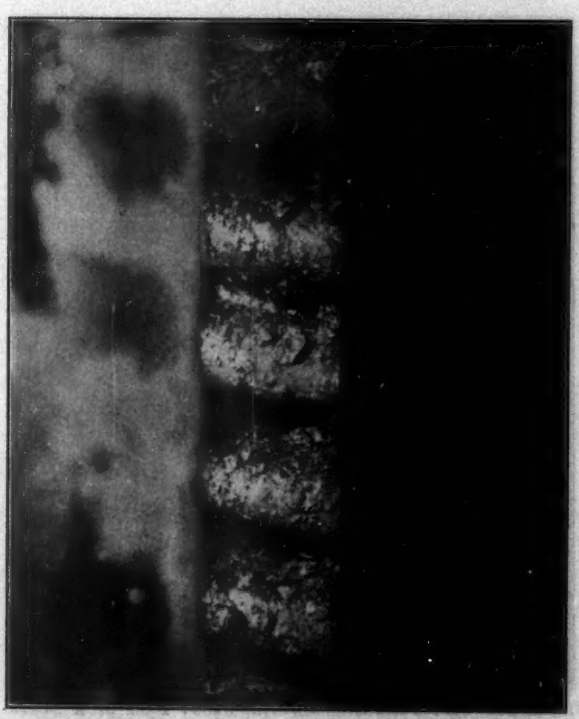

FIGURE 19.—DROP OR CLOT FORMATION EXPOSED BY WASHING OFF LIGHT SURFACE MATERIAL WITH WATER.

FIGURE 20.—CLOT FORMATION ON THE FRONT FACE OF A SUPERHEATER, EXPOSED BY WASHING OFF LIGHT SURFACE MATERIAL WITH WATER.

FIGURE 21.—HARD SLAG DEPOSITS ON FRONT FACE OF A SUPERHEATER.

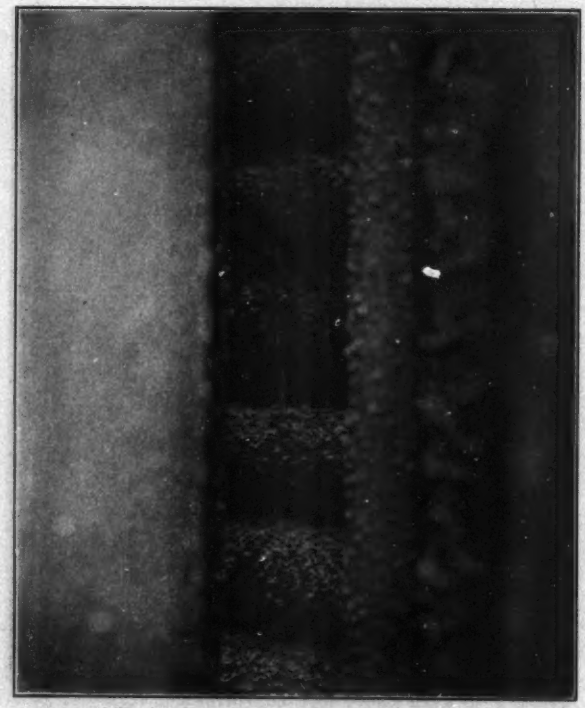

FIGURE 22.—HARD SLAG DEPOSITS ON FRONT FACE OF A SUPERHEATER.

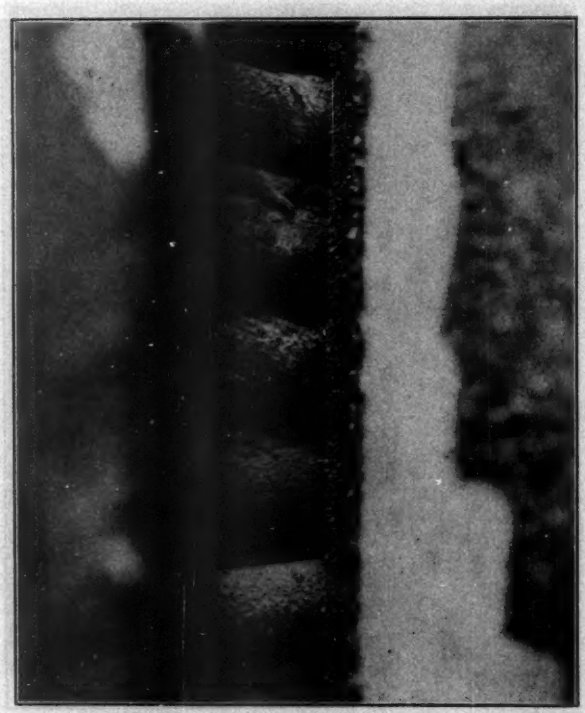

FIGURE 23.—HARD SLAG DEPOSITS ON FRONT FACE OF A SUPERHEATER WHICH HAVE CRACKED LOOSE.

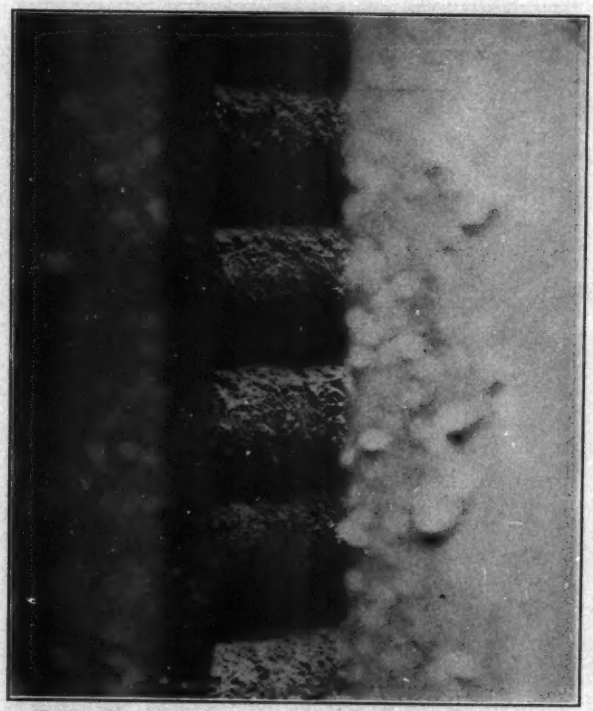

FIGURE 24.—HARD SLAG DEPOSITS ON FRONT FACE OF A SUPERHEATER.

FIGURE 25.—HARD SLAG DEPOSITS ON FRONT FACE OF A SUPERHEATER, SOME OF WHICH HAS SLIPPED.

FIGURE 26.—"WETTED" SCREEN TUBES, SHOWING NATURE OF DEPOSIT ON BOTH THE LEADING AND TRAILING EDGES.

FIGURE 27.—"WETTED" SCREEN TUBES, SHOWING BLISTERS ON THE LEADING EDGE, AND FEATHERS ON THE TRAILING EDGE.

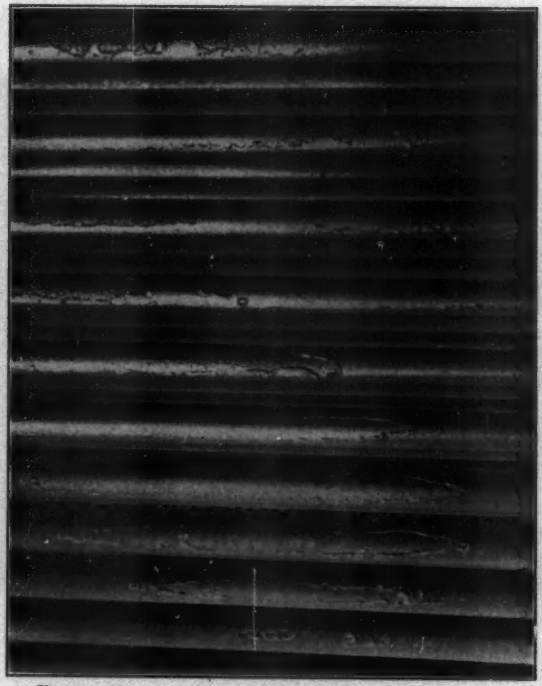

FIGURE 28.—TAR BLISTERS ON THE LEADING EDGE OF SCREEN TUBES.

FIGURE 29.—TAR FEATHERS ON THE TRAILING EDGE OF SCREEN TUBES.

FIGURE 30.—REFER TO FIGURE 25. THE HARD SLAG SHOWN IN FIGURE 25 HAS BEEN CONVERTED TO DRIPPING MUD BY SWEATING WITH ICE WATER.

stick. If dry and coke-like they will probably carom off and stay in the gas stream for some time.

Particles of unatomized oil will probably be unburned, wet, and so large as to be readily thrown out of deflected gas streams. They will spatter, to stick on the first obstruction encountered.

There is little possibility of atomized oil particles, burned while gas-borne, building any form of hard slag deposit. There is considerable probability that unburned atomized oil drops will deposit on tube surfaces in a wet condition. There is considerable probability that unburned and unatomized oil drops will deposit on tube surfaces in a "wet" condition.

Theoretical Considerations Concerning Behavior of Small Particles in Gas Films.

When gas flows through a boiler tube bank, the velocity is probably above critical for all designed loading, and the form of flow is turbulent. A gas film surrounds every obstacle in a gas stream, so there is a gas film around every tube. This gas film has a definite thickness, and tends to adhere to the tube. Gas in actual contact with the tube, remains in contact, and fixed. But immediately beyond contact, there is movement, caused by friction drag. The form of flow here is lamellar. Gas in the lamellar zone increases in velocity as it is further from the surface, increases until critical velocity is attained. The form of flow then converts to turbulent and its forward movement due to drag increases. The acceleration of forward movement constantly decreases, until eventually its velocity merges with that of the stream. The effect of these films can be readily measured, but their actual finite thickness can not. They can only be calculated. Their actual thickness in Naval boilers is probably just a few one hundredths of an inch. They exercise considerable effect on boiler heat absorption, and on boiler draft loss. The temperature of gas films varies across their thickness. At contact, it will be that of the outer surface of the obstacle. At the zone of critical velocity, convention assumes that it is that of the gas stream. The temperature differential then, is confined to the zone of lamellar flow. Gas films exercise two effects upon any small particles carried in the gas stream. Solid particles, before making contact with tube surfaces, will be opposed by a buffer action on

reaching the zone of lamellar flow, and have a tendency to carom off, back into the main stream. Those which penetrate the lamellar zone will be slowed up sharply and tend to be carried for a time parallel to the surface in an ever colder strata of gas. They will tend to be chilled by the colder gas, as well as tend to be chilled by radiation to the nearby tube surface. Both buffer effect and chilling effect will exercise to minimize the probability of molten fly ash actually contacting the surface while still in a molten, or wet, state where it can freeze on. In dry state, particles will probably not stick. If a coating of slag is forming on a tube, the outer surface temperature will increase, eventually to that of melting for the lowest melting ingredient in the slag. The coating will then take a "wet" surface. Both temperature and thickness will stabilize, since additional material can no longer gain a foot hold.

Probable Sequence of Events in Slag Formation.

A study, recently made, of slag formation on the superheaters of a cruiser, seems to point out the sequence of events in the formation of heavy slag.

The superheater in question is a 4 loop superheater in a standard superheat-control boiler which had been recently cleaned by ship's force. They scraped and washed it for two days, using fresh water. Following the cleaning, the boiler operated for about five hours when a failure caused it to be secured.

When first observed, the superheater was in the initial stages of complete tube renewal, some of the tubes having been burned away with cutting torches. Working from the back (furthest from the superheater furnace), the men had removed the 8th and 7th rows, from the top down to about ⅓ of the height. They had also cut into the 6th and 5th rows, but not clear to the top. They were requested to cut a window, about 20 inches square, through the 4th, 3rd, 2nd, and 1st rows, to facilitate examination.

Figure 9 is a typical view of the superheater when looking through the screen tubes of the superheater furnace. The superheater would appear to be clean, according to such an observation.

No photographs had been taken before cleaning; but Figure 3 is the photograph taken of a similar superheater on a sister ship, where the screen tubes had been removed to obtain a less ob-

structed view. It is typical of what might have been expected for Figure 9 before cleaning.

Figure 10 is a photograph at the window, looking up at the bottom of the 1st, 2nd, 3rd, and 4th rows of the superheater, showing the nature of deposits within the tube nest. The vertical tubes at the left are screen tubes. Those on the right are superheat support tubes. Much of the deposit material was dislodged and fell away as the mechanics struggled to cut the window through. Cleaning seems to have done a satisfactory job only on the front tube.

Figure 11 was taken looking up at the back of the 4th row, toward the front of the cavity formed by the legs of the inner loop tubes. It is rather startling, in view of the fact that the superheater had been considered cleaned by the washing prior to tube failure.

Figures 12 and 13 were closeups of the condition illustrated by Figure 11, aimed at giving a little better detail.

In an effort to show conditions further back in the superheater, Figure 14 was taken of material between the 5th and 6th rows. The view was taken looking up, alongside of the 5th row, to the bottom remaining tube in the 6th row.

No attempt was made to photograph conditions beyond the 6th row. Tubes of the 7th and 8th rows were still exposed below, but so much debris had fallen, and been trampled under foot, that validity of such an exhibit would have been questionable. Considerable effort was made to clear away the debris, and it became quite evident that the condition illustrated by Figure 14 obtained also for the gap between the 6th and 7th, and between the 7th and 8th rows. It appeared that the back of the 8th row had a similar condition to that on the 4th row, as shown on Figure 11; though it was possibly a bit lighter.

Slag appears just beyond the screen tubes. The deposit grows in thickness until it is about an eighth inch thick. Apparently at this thickness it can no longer stand the heat stresses involved, at maneuvering. The coating cracks and its bond to the tube is loosened. Flakes, or clots later become detached, heat up and soften, then slide around the tube surface. Deposited material moves. Many of these pieces will drop off, or be blown off, and move further back into cooler zones. In moving, some will jam and become anchored. If the boiler load is reduced they will

freeze and become fixed in position. Being fixed, they will deflect hot gas and stay frozen, as obstacles in the gas stream. Debris will pile up in front of them, as well as in the wake of them, since gas in boiler banks tends to mushroom in all directions to find balanced distribution through each successive plane of tubes. Thus, as nuclei, they start the process of plugging, both before and behind.

Growth of these local plugged areas, along with new ones, finally causes them to merge and thus, large areas become plugged.

Figure 15, looking up under the four front tubes of a superheater, illustrates such a zone of local plugging between the 3rd and 4th rows of tubes.

Figure 16 illustrates the cracking and loosening of a thick slag coating, as well as local plugging.

Figure 17 illustrates the softening and flow of slag on vertical generating tubes.

Figure 18 illustrates cracked off clots which were heavy and dropped down, out of the flow of gas. They have congealed into a very hard and clinker-like mass.

The Cause of Slagging.

Examination of many slagged superheaters has always pointed to the immunity of screen tubes and the vulnerability of those beyond. This seems to indicate a hitherto unrecognized step in the process; one which takes place on the screen tubes. Figure 19 was taken of a DD superheater after some of the surface material had been removed by water washing. A drop, or clot formation is present on the *near* face of the superheater tubes. It provides a condition that is hard to explain in any other way than, the result of a step, in the process, which takes place on the screen tubes.

Figure 20 is a study of bridging by a glass-hard slag on the front face of superheater tubes on a DD. Again, water washing was first employed to clear away some of the outer materials from the deposit. No hard slag had ever been observed on the screen tubes ahead of these superheater tubes. The cracking, then softening, then slipping of slag clots, seems indicated.

Figures 21, 22, 23, 24, and 25, like Figures 19 and 20 all point to a preliminary step in a process which must first take place on

the screen tubes before the superheater tubes are reached. The roughness of coat on the superheater tubes seems to be the result of large particles coming to rest on it; particles infinitely larger than atomized oil could be.

A study of the screen tubes of Figure 9 is presented in another view of them in figures 26 and 27. In these two it can be recognized that atomized oil has impinged on the screen tubes, condensed to a "wetted surface" condition, been carried around the surface to the trailing edges, and "dripped-off" under the drag of passing gas. The whitened fringes at the leading edge are of blister edges which have curled away form the protective tube, and in which the tar has been reduced to ash. The feathers at the trailing edges, like icicles from the porch roof, indicate a "drip" of passing fluid. The general lack of whitened ash fringes on these feathers indicates a fair cooling effect due to volume of flow. Only when they curl sharply away from the radiant cooling of the tube, do they burn and resolve to ash.

Figures 28 and 29 give a little closer view of the blisters and feathers.

On several occasions, immunity of screen tubes to hard slag has been mentioned. While immune to hard slag, screen tubes are seldom clean when observed. Instead, they have a coating of very different nature; one that is very thin, blackened, brittle, cracked, and usually peeling in large flakes. More often than not, it also exhibits some degree of blistering. Its bonding to the tubes is very weak, and rubbing by hand is often sufficient to clean it from the tubes. It is, without question, oil which has not yet been completely burned, and has been found in all stages; oil, tar, coke, and ash.

When the liquid droplets in fogs impinge on obstructions, they are flattened out by the impact to extremely thin films which stick and collect to cause "wetting" of the surfaces. Atomized fuel oil will do this whether it has completely reverted to residual tar, or is still in its original state. Figure 26 and 27 clearly indicate such "wetting", as well as the fact that the collected liquid has blown, in dripping state, from the trailing edges. The normal temperature for screen tube surfaces is between 500-600°F., according to load;—two hundred or more degrees below previous

processing temperatures of "residuals". This is much below ignition temperature, and the residual component cannot burn. It can only drip from tube to tube of the screen, until finally it reaches the hot tubes of the superheater. On its journey it has become enriched in ash:—partly from the ash content of vanished "cutter stock", partly from further cracking and resulting vaporization of "residual stock", and partly from fly-ash entrapped in the sticky tar.

When it finally reaches the superheater, it lands on a surface whose temperature is roughly 950°F. This is well above ignition, so the tar burns there. Drops from dripping tar will be large (relatively), and their ash-enriched skeletons will have similarly large overall dimensions.

It is apparent that screen tubes are immune to hard slag because they have surface temperatures below ignition for residuals. This results in reversion to tar, of the fuel that "wets" them; and of conditioning it into large, oil-clot-like drops. These burn on the hot tubes beyond leaving their skeletons deposited on the surface.

Many slag deposits are soft and chalky, as in Figure 2. Others are sand-paper-like, with a very hard surface as in Figure 21. Still others have the clot formation illustrated in Figure 19. Not all of the unburned oil droplets are strained out on the screen tubes to give the feathers in Figure 29. Many of them carry through to be strained out directly on the superheater tubes. The skeletal remains of these are relatively small in size. They produce the chalky type of deposit illustrated in Figure 2. A chalky deposit which has been laid down at low boiler loading, will melt on later application of high loads. The chalky deposit first crusts over as in Figure 1. Later it becomes sanded as in Figure 21, and finally the solid coating as in Figure 25. The degree of fusion after deposition, with resulting coalescence of the low-fusion components converts the matrix from chalky to a glassy texture, and provides the wide variety in appearance for slag deposits.

If combustion were completed, or change of state from liquid into vapor completed within the furnace, there could have been no "wetting" of screen tubes, nor of slagging which was its direct effect.

Means for Reducing the Incidence of Slag Deposition.

Now that oil impingement is indicated as the probable cause of slag, a great many lines of attack can be outlined for reducing its incidence, such as:—

A. *Modification of oil design.*

1. Use of ash-free oil.
2. Use of ash-free, sulphur-free oil.
3. Use of residual bases, less heavily cracked.
4. Use of heavy distillates.
5. Use of light distillates.

B. *Modification of Boiler Design.*

1. Use of wider tube pitch.
2. Use of lower superheat temperatures.

C. *Modification of Furnace Design.*

1. Higher furnace temperatures at low loads.
2. Improved shape to give longer flame travel.

D. *Modification of Burner Design.*

1. Re-design atomizer for smaller particle size.
2. Use of more and smaller capacity burners.
3. Install burners further from screen.
4. Replace "semi-wide" with "standard" nozzle.
5. Use separate double fronts to avoid throttling of air registers.

E. *Operational, Oil.*

1. Improve water stripping for tanks.
2. Reduce water ballasting of tanks.
3. Improve "settling".
4. Adapt centrifuge removal of water.

F. *Operational, Boiler.*

1. Devise cleanliness "yardstick".
2. Closer observation for cleanliness.
3. Improve cleaning methods.
4. Operate at higher capacity by "floating" unnecessary boilers.

G. *Operational, Furnace.*

H. *Operational, Burner.*

1. Inspect more closely for "semi-wide" boss damage to sprayer plates.
2. Get smaller plates and avoid running with idle registers.
3. Get more sizes of plates to counter trend toward split-plate firing.
4. Use peep-hole rather than smoke indicator to adjust excess air.
5. Throttle air registers as little as possible.
6. Make air and oil adjustments simultaneously.
7. Hold oil pressure above 200 pounds at all times.
8. Hold oil temperature for "special" fuel at 135°F., plus or minus 3°.

There is no question but that the incidence of slagging is proportionate to the amount of attention given to the details of correct operation. No matter how much design may be improved, careless or sloppy operation can easily nullify the improvement.

Some thirty lines of attack have been pointed out above. Not a single one can be spotted as being a positive cure for slagging. Each one has merit that is relative only; some more and some less. The direct observation of several hundred boilers during a study of slag deposits, has led to opinions as to which of the above thirty are most liable to show dividends. These are:—

Use of residuals less highly cracked.

Replacement of the "semi-wide" by the "standard" nozzle.

Improved cleaning methods.

Development of a "yardstick" for measuring cleanliness.

Closer inspection for damage to plates by "semi-wide" nozzle boss.

Confinement of atomizing pressures to the range of 200-300 pounds.

Confinement of atomizing temperature for "special" to within 3° of 135°F.

The refiner, designer, and operator are all involved. Each is in part responsible for the present prevalence of hard slag deposits, and all three must make an effort before a cure can be effected.

The first step indicated is a return to the standard nozzle in atomizers. The unfortunate selection of the "semi-wide range" as a name for the currently used nozzle has provided a psychology leading to neglect of many "first principles" for good atomization; as well as introducing a structural failure which, in general, goes undetected.

METHODS FOR REMOVAL OF DEPOSITS.

Mechanical removal of hard slag from superheaters is obviously impossible; due to hardness of material, tenacity of bonding, and lack of accessibility. Removal by water provides the only means presently at hand. Water can remove slag by putting it into solution, but it cannot remove by force a slag so hard that hammer blows will only succeed in pulverizing its face. Many hard slags will even cut glass. Moreover, study of the included photographs illustrate the utter impossibility of forcing a hard stream to penetrate the tube bundle much beyond the face.

It can be safely assumed that all slags are nearly three quarters water soluble,—if given long enough exposure to water. The harder slags are, the more time will be required for putting them into solution. Like sun dried adobe mud, it may take a few hours to penetrate as much as an eighth of an inch. In addition, plugged tube lanes must be opened by slow solution before plugged lanes farther in can be exposed. Hard streams are useless, besides presenting a very troublesome problem from the volume of water involved. Slow and easy does it. The writer has cleaned several superheaters by sweating;—Insert a blank gasket in the saturated line to isolate the superheater from the boiler. Then circulate water through the superheater, cold enough to cause air moisture to condense on the outer (slag) coating. Air will filter through almost any gas lane, no matter how badly plugged, and carry air moisture with it. There are no shielded areas. All heating surfaces (or their coatings) can be reached. There is no surplus water to contend with. A spare water rheostat box can be set on deck for storage of circulating water, and a couple of 1½" fire hose sections used to connect it to the superheater so that water can be drawn from the box with a portable submersible pump, driven via the superheater drain connection, through the tubes, and out through the temperature control connection, back into

the box. Cakes of ice can be dumped into the water box from time to time, and ice water circulated. This appears to be a very expensive way of making water. It is;—but it is a very cheap way for putting water where it can act. In an emergency, a coffer dam, or fore peak can be used for cooling water; and air moisture augmented by a little steam from a steam lance. Circulation of air through the superheater must be provided, of course. Figure 30 shows a destroyer superheater being "sweated" with ice water. An air lance will readily remove the dripping muck.

METHODS FOR BUILDING A YARDSTICK TO MEASURE CLEANLINESS.

The plugging of superheaters takes place in areas permitting neither visibility nor accessibility. An observation of the outer front face gives no indication of condition, and only results in a false and dangerous sense of security. Effective inspection methods must be devised. The writer has been in the habit of using measured performance of the superheater to indicate its state of cleanliness. The method is outlined as follows:—Fouling of superheater tubes requires more heat to produce the designed 850 temperature, which means increased oil to the superheater furnace and less to the saturated furnace. All boiler instruction books detail the relative fuel weights to each furnace for the whole range in loading as measured, under test, or clean conditions. In general 50 to 55% of the total fuel must be fired in the superheater furnace of a clean boiler to produce the designed steam temperature. Comparison between actual and test requirements will provide a simple and suitable yardstick. Or, better yet, a continuous record can be made of the percentage of total oil required by the superheater furnace for some given, common, load condition.

Whenever a superheater is cleaned, record of the relative fuel weights required before and after cleaning, should be the criterion for the degree of cleanliness, actually attained.

A very grave danger exists for combat ships, in that progressive growth of slag deposits if not kept under observation, may not be discovered until ship power has been definitely crippled. The need for developing a cleanliness yardstick cannot be over emphasized.

LETHAL ATMOSPHERES PRODUCED BY THE GROWTH OF MICROORGANISMS IN CONFINED SPACES.*

BY DAVID F. RICHARDSON AND OSCAR I. MILNER.†

I. INTRODUCTION.

It has long been known that when organic matter is decomposed by growing microorganisms a great variety of degradation products are formed. In the case of cellulose, Thaysen and Bunker (1) and Waksman (2) have observed that these may include ethyl alcohol, acetic, propionic, butyric and lactic acids, methane, hydrogen, and carbon dioxide. It is equally well known that in this decomposition process oxygen is simultaneously consumed. However, it does not appear to have been sufficiently emphasized that if the growth takes place in an enclosed space in which the supply of air is limited, and the volatile decomposition products are prevented from escaping, a lethal atmosphere may result.

The danger of atmospheres so developed was pointed up in two recent instances where Navy bluejackets were overcome on entering confined and unventilated ships' compartments without observing prescribed safety precautions. In both instances the compartments were of small capacity and were used for the storage of protective covers for shipboard bedding; these covers, or bedding bags, had been manufactured from a coated, flameproofed fabric conforming to a Navy Department specification (3).

Investigation in connection with these two accidents established the fact that in both cases atmospheres high in carbon dioxide were present within the compartments when the victims entered. In the first an analysis showed carbon dioxide in excess of 11 per cent; the oxygen content was not reported. In the second instance the compartment was not immediately sealed after the accident but remained open for at least thirty minutes; subsequent analysis of the atmosphere showed the following composition, in per cent by volume: nitrogen—80;

* The opinions expressed in this paper are those of the authors and do not necessarily reflect those of the Navy Department.

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oxygen—14.6; carbon dioxide—5.4. In both of the compartments in question a musty odor was detected, and in one the bedding bags were visibly mildewed.

II. Experimental.

Immediately following the report of the first accident, the writers were requested to investigate the possibility that the flameproofed fabric which was stored within the compartment might have decomposed upon prolonged storage—with the liberation of toxic gases—and to determine the causes for such decomposition in the event that it occurred. Emphasis was initially placed upon the fact that the fabric in question was flameproofed, and that toxic atmospheres might have resulted from a purely chemical decomposition of the treated material. However, it had been previously observed at this laboratory (4) that mildew growth on cork gasket material in a closed damp system had resulted in the complete exhaustion of oxygen and the liberation of high percentages of carbon dioxide. Preliminary tests, involving inoculation of representative samples of the flameproofed materials with mildew spores as described in the General Specification for Inspection of Material (5), demonstrated that they were also subject to attack by microorganisms with the simulataneous formation of atmospheres containing 15 to 20 per cent carbon dioxide and practically no oxygen. It was considered important, therefore, that the investigation furnish information on the possible effects of storing the material in a damp condition as well as in normal dry storage.

Six samples of flameproofed fabric, all coated with compositions involving vinylite resins, and a control sample of unbleached cotton sheeting (6) were selected for exposure. The specification covering the bedding-bag material is primarily based upon performance and does not prescribe the composition of either the flameproofing treatment or of the coating. Under the original editions fabrics treated with water-soluble flameproofing compounds were supplied; later revisions of the specification included requirements which could be met only by materials which are not readily leached from the fabric. Attempts were made to include in the six selected all types which had been procured by the Navy. In the following paragraphs those materials flameproofed with water-insoluble compounds are identified as samples

A, B, and C and those involving water-soluble formulations are designated D, E, and F. The control is identified as sample G.

Exposure conditions were chosen to simulate as closely as possible those on shipboard, which involved the storage of a large number of flameproofed bedding bags in an infrequently opened airtight compartment. Four-square yard samples of each of the materials were placed in galvanized metal containers of 1 cubic foot capacity. Each container was fitted with a gasketed lid which could be fastened to form an airtight seal, the lid containing a pet-cock arrangement to permit the withdrawal of air samples for analysis. Duplicate sets of containers were provided; in the first the samples were enclosed and the containers sealed at the prevailing humidity (35 per cent), while in the second air at 100 per cent relative humidity was passed through the containers for 72 hours prior to sealing. These sets are hereinafter referred to as Series 1 and Series 2 respectively. All containers were stored at a controlled temperature of 80° F.

At one-month intervals pressures were equalized by momentarily opening the pet-cock, and samples of the atmospheres were withdrawn and analyzed for carbon dioxide and oxygen content. This procedure was followed for three months. During this time there was, in every case, a gradual decrease in the oxygen content, usually with a corresponding increase in the amount of carbon dioxide present. In general, this was true of both series; however, in most instances the percentages of carbon dioxide found in the containers of Series 2 were significantly higher than those of Series 1. Because of this, those containers of Series 2 which contained the coated bedding-bag fabrics were opened at that time and examined for suspected mildew growth.

Significantly, sampes E and F, which had liberated more carbon dioxide than any of the other coated fabrics (as shown below) were found to be slightly mildewed. These observations showed that at least some of the materials would be spontaneously attacked in a damp atmosphere and verified the preliminary test results which had indicated that this growth would be accompanied by the liberation of carbon dioxide and consumption of oxygen. Therefore, to reproduce the effects of a more thorough saturation of the materials such as might result from leakage of water into a closed compartment in which they were stored, all of the coated fabrics of Series 2 were sprayed with tap

water and resealed. The containers were then stored as before for an additional three-month period. However, to determine whether the decomposition would become accelerated without any modification of conditions, the control chamber was kept sealed for an additional two months before being sprayed.

III. Results.

The results of the atmospheric analyses for the entire exposure are presented in Table 1.

During the first three months, as shown by the data of columns 1 to 3 of the table, changes were gradual and of small magnitude. As stated previously, there was in every case a gradual decrease in the oxygen content, usually with a corresponding increase in the amount of carbon dioxide present. The greatest change was produced by the control sample of Series 2, which showed an oxygen content of 16.4 per cent and a carbon dioxide percentage of 3.6 at the end of this period. In this series two of the coated fabrics, samples E and F, also liberated relatively high percentages of carbon dioxide—1.8 and 2.2 per cent respectively.

In the second three-month period (from the data as presented in columns 4 to 6 of the table) the atmosphere of the dry chambers continued to show comparatively insignificant alterations. However, critical changes in the percentages of carbon dioxide and oxygen took place in all of the damp chambers; these changes invariably occurred within a month after the supplementary wetting. The greatest effect noted was again that in the control exposure. In this instance the percentages of carbon dioxide and oxygen were 6.4 and 13.2, respectively, by the end of five months (without additional treatment); supplementary wetting at this time caused the carbon dioxide to rise to 27.6 per cent within one month, with essentially complete exhaustion of the oxygen. The case for the coated fabrics is not so simple; all except sample C showed exhaustion of the oxygen within one month after the supplementary wetting, but only sample E developed an approximately equivalent carbon dioxide concentration. The consumption of oxygen by sample C was accelerated by the wetting, but was still much less than that of the other fabrics; no carbon dioxide could be detected in the atmosphere over this material.

In addition to the depletion of oxygen and generation of carbon dioxide by the sample of Series 2, other significant changes

TABLE 1.

OXYGEN AND CARBON DIOXIDE CONTENT OF ATMOSPHERE.

Sample	Series	Gas	MONTHS 1	2	3	4	5	6
A	1	O_2	21.0	20.8	20.5	20.4	20.2	20.2
		CO_2	0.2	0.2	0.1	0.2	0.2	0.2
	2*	O_2	21.0	20.6	20.5	0.8	0.6	0.2
		CO_2	0.0	0.1	0.1	8.6	9.2	9.8
B	1	O_2	21.0	20.6	20.4	20.2	20.0	19.9
		CO_2	0.2	0.1	0.2	0.4	0.5	0.5
	2*	O_2	20.8	20.2	20.1	0.5	0.3	0.0
		CO_2	0.0	0.8	0.6	13.0	16.4	17.0
C	1	O_2	20.8	20.2	20.0	19.4	19.4	19.4
		CO_2	0.0	0.5	0.5	0.6	0.6	0.6
	2*	O_2	20.4	20.2	19.4	17.5	16.6	15.0
		CO_2	0.3	0.5	0.6	0.0	0.0	0.0
D	1	O_2	21.0	20.8	20.1	19.4	19.6	18.7
		CO_2	0.2	0.7	1.0	1.0	1.0	1.5
	2*	O_2	20.8	20.4	20.3	1.0	0.7	0.5
		CO_2	0.6	0.8	0.9	10.4	11.0	10.6
E	1	O_2	21.2	20.8	20.7	20.4	20.4	20.2
		CO_2	0.0	0.0	0.0	0.2	0.0	0.2
	2*	O_2	20.7	20.5	19.6	0.8	0.2	0.3
		CO_2	0.3	1.0	1.8	19.4	23.2	23.7
F	1	O_2	21.0	20.9	20.6	20.8	20.0	20.2
		CO_2	0.0	0.2	0.2	0.2	0.7	0.4
	2*	O_2	20.6	20.1	19.7	0.8	1.0	1.0
		CO_2	0.8	1.3	2.2	6.0	2.4	3.0
G	1	O_2	21.2	21.2	20.6	20.6	20.6	20.4
		CO_2	0.0	0.0	0.0	0.0	0.0	0.0
	2†	O_2	21.0	19.0	16.4	13.6	13.2	0.3
		CO_2	0.0	1.5	3.6	5.8	6.4	27.6

Notes: * Sprayed at end of 3 months and resealed.
† Sprayed at end of 5 months and resealed.

occurred. All showed visible evidence of microorganism growth on the fabric and/or the coating. Examination revealed the presence of bacteria, actinomyces, and various fungi including Aspergillus and Penicillium. The mildewing was generally accompanied by the liberation of odors suggesting the presence of lactates, butyrates, and acetates. This was particularly true of samples B, D, E, and G. Sample C showed only one patch of mildew on the coating and no abnormal odor. Sample F, which gave only slight visible evidence of mildew growth, yielded a penetrating ammoniacal odor, the atmosphere being found to contain 670 p.p.m. of gaseous ammonia; microscopic examination revealed extensive bacterial growth. Analysis of this sample showed that the finished material contained 2.7 per cent of inorganic nitrogen (as combined ammonia), 3.1 per cent of sulfur (as sulfate), and 0.7 per cent of phosphorus (as phosphate), suggesting the presence of ammonium sulfate and phosphate which are commonly used as ingredients in flameproofing treatments.

IV. Discussion.

The results of the exposures of Series 1 are considered as indicating the possibility of partial oxidation of the various coating materials or treated fabrics over a prolonged period of time. However, there was a similar decrease in oxygen content of the control chamber—apparently due to slight oxidation of the cellulose—and it is therefore believed that dry storage of such treated materials as were included in this investigation would offer little special hazard during a limited exposure. Accordingly, further discussion will be limited to the samples of Series 2.

In most instances the atmospheric alterations after three months' exposure at high humidity were somewhat greater than in the companion exposures, and appear to have been associated with microorganism activity. In the case of samples E and F, fungous vegetation had already been established when the materials were examined; in the other flameproofed fabrics the spores had evidently not yet germinated and little decomposition had occurred at the time of opening. It is also significant that the exposure of the control sample resulted in similar and more extensive changes. While this container was not opened for inspection at the same time as the others, considering the widespread growth subsequently found, examination after three months would undoubtedly also have shown visible mildew.

The rapid and extensive changes brought about by the supplementary wetting constitute the most striking development in connection with the investigation, and were unquestionably due to the stimulation of fungous and bacterial activity. In view of the chemically heterogeneous nature of the materials studied, and the limited scope of the work, no comprehensive study of the decomposition has been attempted. As has been indicated in the Introduction, various investigators have observed that even in the relatively simple case of cellulose alone the decomposition products may be many and varied. The coatings and fire-retardant treatments applied to the fabrics of this investigation would be exposed to increase the diversity of these products; for example, ammonia has been reported present in the case of sample F.

Certain apparent anomalies in the experimental data merit consideration. In most cases, particularly those of samples C and F, the decrease in oxygen content was far greater than the corresponding increase in carbon dioxide. In addition, samples D and F actually show a slight decrease in carbon dioxide at certain intervals during the second three-month exposure. However, these results are not surprising in consideration of the possible reactions, among which are:

(1) Assimilation of oxidation products by the organisms themselves.

(2) Formation of intermediate oxidation products, such as oxycellulose.

(3) Removal of carbon dioxide from the atmosphere through combination with alkaline components or decomposition products. (This evidently occurred in the case of sample F, which yielded ammonia and at the same time showed a powdery deposit of ammonium carbonate.)

(4) Utilization of carbon dioxide in the growth of microorganisms or in spore formation. (The latter phenomenon was postulated in connection with a periodic decrease in the rate of carbon dioxide evolution observed by Rogers and co-workers (7).)

Whatever the process by which the decomposition is accomplished, the most significant aspect is the generally complete exhaustion of oxygen within one month after the sprayed samples were sealed. Exposure to the resultant atmospheres would

unquestionably prove rapidly fatal, regardless of the presence or absence of other noxious gases. Only in the case of sample C was the final oxygen concentration considered sufficiently high to permit survival after a short exposure; significantly, this sample showed only one small area of mildew growth on the coating, possibly due to fungicidal properties on the part of zinc borate which was included in this particular flameproofing compound. With this sole exception all of the sprayed samples, including the untreated control, produced lethal atmospheres.

While the writers did not personally observe the conditions surrounding the two cases of collapse which gave rise to this investigation, it is evident that they resulted to a large extent from the oxygen depletion caused by the growth of microorganisms on the bedding bag fabric. However, it is equally evident that storage in a confined space of any other organic material capable of supporting mildew growth would be similarly hazardous. Such storage should either be strictly prohibited, or the exercise of adequate precautions, including testing of the atmosphere followed by thorough ventilation, should be required prior to entry into questionable spaces.

V. Summary.

The results obtained upon six months' storage of representative flameproofed cotton-base fabrics in a sealed compartment indicate that at low or moderate humidity only minor atmospheric changes are produced; high humidity causes rapid depletion of the oxygen and the liberation of excessive amount of carbon dioxide. This is due to the growth of various microorganisms on the damp organic matter and is not directly related to the coating or flameproofing treatment.

Under certain conditions the atmospheric alterations thus produced in confined spaces are sufficiently extensive to prove fatal to personnel who might enter. Entry into compartments in which mildewing is apt to have occurred should therefore be accompanied by the exercise of adequate precautions.

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(3) Navy Dept. Specification 27F11 for Fabric, Coated, Flameproofed (for Bedding Covers).

(4) Industrial Test Laboratory Report No. 6064 dated 8 August 1946—"Mildew Resistance of Packing and Gasket Materials" (unpublished).

(5) General Specifications for Inspection of Material, Appendix IX—"Mildew Resistance of Organic Materials (Textiles, Leather, etc.), General Specification of Methods for Determination of"—Bureau of Ships Ad Interim Issue dated 15 June 1945.

(6) Navy Dept. Specification 27S11a for Sheeting, Cotton, Bleached and Unbleached, Preshrunk, dated 15 January 1946.

(7) Rogers, R., Wheeler, H., and Humfeld, H., "Physical and Chemical Changes Produced in Bleached Cotton Duck by Chaetomium globosum and Spirochaeta cytophaga"—Tech. Bull. No. 726, U. S. Dept. of Agric., March 1940.

COMPARISON OF ELECTRIC SHIP PROPULSION WITH OTHER TYPES OF DRIVE.

By J. B. Friauf and N. T. Jucarone (Civil Members).

Introduction.

Electric ship propulsion was provided for an appreciable percentage of U. S. Naval vessels constructed shortly prior to and during the recent war. These vessels included submarines and surface vessels of such types as destroyer escorts, tenders, tankers, transports, minesweepers, salvage vessels, net laying ships, tugs, and ferry boats. The total number of electric drive U. S. Naval vessels reached a peak in excess of one thousand shortly after the end of hostilities. In these recent applications the total shaft horsepower per vessel ranged from a maximum of 20,000 SHP to a minimum of about 300 SHP.

Although the application of electric ship propulsion in naval vessels was introduced several decades prior to the recent war, its early use was rather limited. A total of seven battleships and two aircraft carriers constructed during and shortly after World War I were equipped with turbine-electric alternating current drives, and for many years prior to World War II submarines were equipped with Diesel-electric direct current drives. Electric drive was selected for these early battleships and carriers primarily because the advent of high speed, large capacity steam turbines and the lack of experience in the manufacture and use of high capacity reduction gears for marine service indicated the need for a drive which would provide the required speed reduction between the steam turbines and propellers without the use of high capacity reduction gears. Other advantages, such as increased flexibility and increased fuel economy at cruising speeds, were also anticipated in these capital ships. The application of electric ship propulsion in submarines was dictated by the necessity of operating submerged with large storage batteries as the only source of propulsion power. Although the earlier submarines utilized electric propulsion only when submerged, and direct or geared Diesel drive when surfaced, the propelling plant eventually

developed into the present type which utilizes electric ship propulsion for both submerged and surfaced operation.

The recent use of electric drives in naval surface vessels has been more extensive and more varied as to quantity and types of vessels. This was brought about by a number of considerations, the major ones being:

(*a*) The Navy's experience with electric drive, though limited, had demonstrated its acceptability. In addition, much development and favorable experience had been accumulated in commercial marine applications.

(*b*) The immense demand for propelling machinery necessitated the use of steam turbines and Diesel engines of designs and capacities that could be produced most rapidly and in largest quantities. With the electric drive, medium capacity steam turbines and higher speed Diesel engines of established designs and ratings could be utilized.

(*c*) The need for reduction gears could be eliminated. During the recent war the demand for reduction gears exceeded the supply and the resulting bottleneck was an important consideration in the decision to employ electric drive in many naval vessels.

(*d*). The inherent advantages of electric drive for certain naval applications could be realized.

If the considerations determined primarily by wartime exigencies are discounted, the electric drive as a form of ship propulsion must be compared with other types of drive on the basis of its merits in order to ascertain the most likely fields of application for electric ship propulsion. It is the purpose of this article to:

(*a*) Enumerate those features which are desirable in naval propulsion instaliations.

(*b*) Enumerate which of these features are readily obtainable with the several types of electric drive, which include the following:

Diesel-electric, D-C

Diesel-electric, A-C, Synchronous motor*

* Polyphase squirrel cage or wound rotor induction motors were employed in the early capital ships previously referred to. However, in all the more recent naval applications of a-c electric drives, synchronous motors have been employed because of their lighter weight, smaller size and higher efficiency as compared with induction motors of equivalent capacity. Accordingly, induction motors will not be considered in detail herein.

Diesel-electric, A-C, Electronic control
Turbine-electric, D-C
Turbine-electric, A-C, Synchronous motor*
Turbine-electric, A-C, Electronic control.

(*c*) Discuss installations with multiple prime movers per shaft, particularly with reference to overload capacity required to obtain the most desirable performance from these installations.

(*d*) Summarize in tabular form for purposes of ready comparison, the characteristic features of the different types of electric drive listed above (all with fixed pitch propellers) and the following types of mechanical drive:

Geared turbine, fixed pitch propeller
Geared or direct drive Diesel, fixed pitch propeller
Geared turbine, controllable and reversible pitch propeller
Geared or direct drive Diesel, controllable and reversible pitch propeller.

Desirable Features For A Propulsion Installation.

Basic requirements. Basic requirements for a naval ship propulsion installation are:

(*a*) Ability to propel and maneuver the ship ahead and astern.
(*b*) Reliability.
(*c*) Efficiency.
(*d*) Simplicity of operation.
(*e*) Ease of maintenance.
(*f*) Lightest weight and smallest space consistent with the above.

No installation which does not meet all these requirements to a satisfactory degree is suitable for a naval installation no matter how advantageous it may be in some respects.

Desirable features. In addition to the basic requirements listed above, the following features are desirable.

(*a*) The installation should provide a speed reduction so that high-speed prime movers and the slow-speed propellers they drive can both operate at optimum speed.

(*b*) The installation should provide for uncoupling the propeller shafts from prime movers.

(*c*) The installation should provide approximately rated torque astern as well as ahead.

(*d*) The installation should provide for changing the propeller speed either continuously or in small steps over the entire range from maximum propeller speed ahead to maximum propeller speed astern, and for operating continuously at any speed in this range.

(*e*) The installation should provide for delivering rated output from the prime movers irrespective of changes in the ship's resistance, due to hull fouling, changes in displacement, etc.

(*f*) The power for each shaft should be furnished by several independent prime movers, rather than by one prime mover per shaft.

(*g*) Installations with multiple prime movers per shaft should have characteristics such that the rated power output of each prime mover in use can be supplied to the shaft whether all or only some of the prime movers are in service.

(*h*) In an installation with only one prime mover per shaft it may be desirable in some cases to have the installation so arranged that one prime mover can drive two shafts at reduced speeds.

Brief discussion of desirable features. Speed reduction is desirable because it permits the combination of efficient low-speed propellers and modern high-speed (light weight) prime movers. A speed reduction is provided in most naval propulsion installations, the major exceptions in recent years being direct connected steam or Diesel engines used in some vessels.

The ability to uncouple the propeller from the prime mover and the ability to provide rated torque astern are found in all types of electric drives and in some types of mechanical drive. They are not provided in the geared turbine drives used in naval vessels.

Smooth speed control over the entire range of speed is highly desirable for steaming in formation and for maneuvering. This feature is provided by direct current electric drives and geared turbine drives. Smooth speed control is not provided in the low speed range by alternating current synchronous motor drives, or by geared or direct Diesel drives with fixed pitch propellers.

The ability to adjust the speed of the propeller in a manner so that rated output is obtained from the prime movers despite variations in the ship's resistance from rated value as a result of hull fouling, displacement changes, etc., is highly desirable and will be considered further in succeeding paragraphs.

The desirable features relating to multiple-prime-mover installations are considered in succeeding paragraphs, particularly in connection with electric drives, which provide the most flexible method of realizing these features.

The ability to drive two shafts from one prime mover may be desirable in installations with one prime mover per shaft. Electric propulsion is probably the only feasible means for realizing this feature. It is provided in most turbine-electric A-C vessels with one prime mover per shaft, but not in the Diesel-electric D-C vessels with two or more prime movers per shaft.

Multiple-Prime-Mover Installations.

Advantages. An installation in which several independent prime movers are used to supply power for each shaft has the following advantages:

(*a*) It provides greater reliability because the loss of one prime mover as the result of an operating casualty or battle damage will not cause loss of all power to the shaft. Furthermore, one prime mover can be shut down for maintenance while under way, if necessary.

(*b*) It provides a more efficient arrangement for cruising.

(*c*) It provides the most suitable way of using those types of prime movers which cannot be built large enough in single units to furnish the total power needed by one shaft.

Limitations on number of prime movers. There is no definite limit to the number of prime movers that can be used per shaft in multiple-prime-mover installations. Considerations which bear on this are as follows:

(*a*) It is not desirable to have too many prime movers in the same machinery space, because a missile which damages one of the prime movers may damage others.

(*b*) It is not desirable to put multiple prime movers in a large number of different spaces, because this complicates control equipment and increases the number of operating personnel required.

(*c*) Since there is only one control station for each shaft and propeller, the reliability of the entire propulsion plant for each shaft and propeller is not correspondingly increased by an increase in the number of prime movers even though this improves the reliability of the propulsion power supply.

(*d*) It is probable that not more than four prime movers per shaft are needed to take full advantage of the increased reliability and higher cruising efficiency which can be obtained with a multiple-prime mover installation. However, if the prime movers used are of a type which is available only in units of relatively small capacity, it may be necessary to exceed four prime movers per shaft in order to obtain the required shaft horsepower.

Power obtainable from multiple-prime-mover installations. In some types of multiple-prime-mover installations, the rated power output of each prime mover which is in use for propulsion can be applied to the shaft irrespective of whether some or all of the prime movers are in use; in others, rated power output from each prime mover can be obtained only when all the prime movers installed are in use. The first mentioned types are preferable, since a larger percentage of the total installed horsepower is available for propulsion when some of the prime movers are shut down. This is the desirable feature listed as (g) on page 177. What it means, and the differences between installations which do and do not have this feature, will be considered in detail below, after a statement of the assumptions and definitions used and a brief discussion of propeller characteristics and power transmissions.

Assumptions And Definitions.

The following assumptions and definitions are used throughout the remainder of this article:

(*a*) It is assumed that the individual prime movers installed in multiple-prime-mover installations are of equal power.

(*b*) It is assumed that the same number of prime movers is installed for each shaft of a multiple-propeller ship. It is also assumed that, at any given time, the number of prime movers used for propulsion is the same for each shaft. N is used to denote the number of prime movers installed for each shaft, and

n for the number in use per shaft. In view of the foregoing assumptions, n/N will be the same for all shafts and will range from zero, when no prime movers are in use, up to unity, when all are in use for propulsion.

(*c*) It is assumed that the propulsion plant and propellers are perfectly matched to each other and to the ship, so that when all prime movers are in use and are operated at rated speed, they will develop rated torque and power, and supply rated shaft power to turn the shaft at rated propeller speed when the ship's displacement, condition of bottom, and other conditions which affect ship's resistance all have the values for which the plant is designed.

(*d*) The force required to move a ship through the water at a constant speed is equal and opposite to the resisting force which opposes motion of the ship. This force depends upon the speed of the ship and numerous other factors which include, for example, ship's displacement and extent of fouling of the bottom by marine growth. The statement that the ship's resistance is at rated value will mean that all factors which affect the ship's resistance, *except ship speed*, have the rated values for which the installation is designed, that is, rated displacement, clean bottom or specified condition of fouling as the case may be, and so on. Under rated conditions, the resistance which opposes motion of the ship at constant speed will depend only upon ship speed; and at each speed will be equal to the rated value for that speed.

(*e*) Overload capacity is defined to be the ability of any part of the propulsion installation to do more than is required for operation under rated conditions as outlined in paragraph (c) on page 180. For instance, ability of a prime mover, generator, or motor to develop more than rated power at rated speed or above, or to develop rated power at less than rated speed, would be examples of overload capacity.

(*f*) Ship speed, propeller speed, torque and power to turn the propeller, and analogous quantities will be expressed as decimal fractions of the rated value of the corresponding quantity. For example, a ship speed of 0.50 will mean a ship speed equal to 0.50 times the rated speed.

(*g*) Except where otherwise noted, the electrical and mechanical losses in the propulsion system will be neglected.

Propeller Characteristics.

Speed, torque, and power. When all conditions which affect the ship's resistance except ship's speed are constant, for steady operation at any ship speed the characteristics of a fixed pitch propeller are given approximately, but with sufficient accuracy for this general survey, by the following relations:

(*a*) Ship speed is directly proportional to propeller speed.

(*b*) Propeller torque is directly proportional to the square of propeller speed.

(*c*) Shaft power is directly proportional to the cube of propeller speed.

Since the ship, propulsion plant, and propeller are assumed to be perfectly matched to one another, when the ship's resistance has its rated value, the ship speed, propeller torque, and shaft power will all be at their rated values when the propeller is turning at rated speed.

If fouling of the ship's bottom, increase in displacement, or some other cause increases the ship's resistance to more than its rated value, when the propeller is turning at rated speed:

(*a*) Ship speed will be *less* than rated ship speed.

(*b*) Propeller torque will be *more* than rated propeller torque.

(*c*) Shaft power will be *more* than rated shaft power.

Variable And Fixed-Speed Ratio Transmissions.

The transmission which an electric or mechanical drive provides between the prime mover (or prime movers) and the propeller may be a variable or a fixed-speed ratio transmission. With the former, the ratio of propeller speed to prime mover speed can be varied by the operator. With the latter, the ratio of propeller speed to prime mover speed is fixed and cannot be varied by the operator. The characteristics of typical installations are as follows:

D-C Electric drive	Variable
A-C Synchronous motor	Fixed
A-C Electronic control	Variable
Geared turbine	Fixed
Geared or direct drive Diesel	Fixed

It is to be noted that in some types of fixed-speed ratio installations, for example, electric drives with A.C. synchronous motors, the ratio between prime mover speed and propeller speed varies during the periods in which the propeller is started or reversed. However, as soon as the transition period ends and the motor is synchronized, the ratio between prime mover and propeller speeds is fixed at a definite value which depends upon the design of the installation and which cannot be varied by the operator. In other types of fixed-speed ratio installations, for example, a geared turbine drive, the ratio between turbine speed and propeller speed is the same at all times, including the periods during which the propeller is started or reversed.

The variable-speed ratio transmission has several advantages as compared with a fixed-speed ratio transmission. This will become apparent in subsequent paragraphs dealing with Diesel-electric installations.

Diesel-Electric Installations.

Engine characteristics. The power output of a Diesel engine is directly proportional to mean effective pressure (MEP) times engine speed. It is not permissible (except in an emergency) to exceed *either* the rated MEP or rated speed. Because of these limitations, it follows that:

(*a*) Rated power can be obtained only when MEP and speed are both equal to their rated values.

(*b*) Maximum permissible power is obtained at any engine speed when the mean effective pressure is equal to the rated MEP. The maximum permissible power obtainable is therefore directly proportional to engine speed. This relation is shown graphically in Figure 1, in which power and speed are expressed as fractions of their rated values. If, for example, the engine is running at 0.6 rated speed, the maximum permissible power that can be obtained is 0.6 rated power. Of course, any power less than this can be obtained at the same speed by operating the engine at less than rated MEP, which is permissible provided that the engine is not loaded so lightly that fouling results.

(*c*) The Diesel engine has no overload capacity as defined in paragraph (*e*) on page 180. It cannot, without exceeding rated MEP or rated speed, deliver more than rated power at any speed;

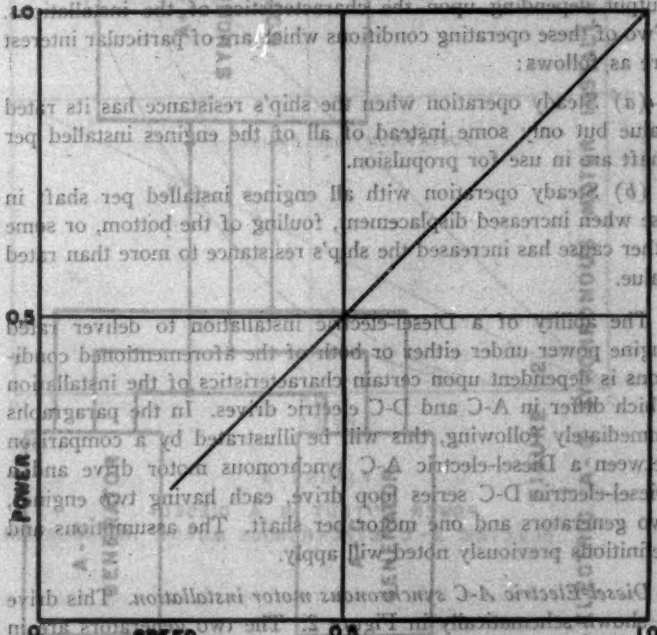

FIGURE 1

DIESEL ENGINE OUTPUT WITH MEP CONTANT AT RATED VALUE

nor can it deliver rated power at less than rated speed, without exceeding rated MEP.

Delivery of rated engine power to the shaft. When operating under rated conditions as outlined in paragraph (*c*) on page 180, all engines will deliver rated power output. There are, however, other operating conditions under which the engines being used for propulsion may or may not be able to deliver rated power output depending upon the characteristics of the installations. Two of these operating conditions which are of particular interest are as follows:

(*a*) Steady operation when the ship's resistance has its rated value but only some instead of all of the engines installed per shaft are in use for propulsion.

(*b*) Steady operation with all engines installed per shaft in use when increased displacement, fouling of the bottom, or some other cause has increased the ship's resistance to more than rated value.

The ability of a Diesel-electric installation to deliver rated engine power under either or both of the aforementioned conditions is dependent upon certain characteristics of the installation which differ in A-C and D-C electric drives. In the paragraphs immediately following, this will be illustrated by a comparison between a Diesel-electric A-C synchronous motor drive and a Diesel-electric D-C series loop drive, each having two engines, two generators and one motor per shaft. The assumptions and definitions previously noted will apply.

Diesel-Electric A-C synchronous motor installation. This drive is shown schematically in Figure 2. The two generators are in parallel. When the motor and generators are in synchronism, the speed ratio between the prime movers and propeller is fixed by the relative number of poles on the generators and motor, and cannot be changed by the operator. Propeller speed is changed by changing the engine speed. Diesel engines are not normally operated continuously at speeds below about 0.25 rated speed because of excessive fouling which occurs at such reduced speeds. This installation, therefore, does not permit continuous operation at all speeds over the entire range of propeller speed, which was listed as desirable feature (*d*) on page 177. It gives smooth speed

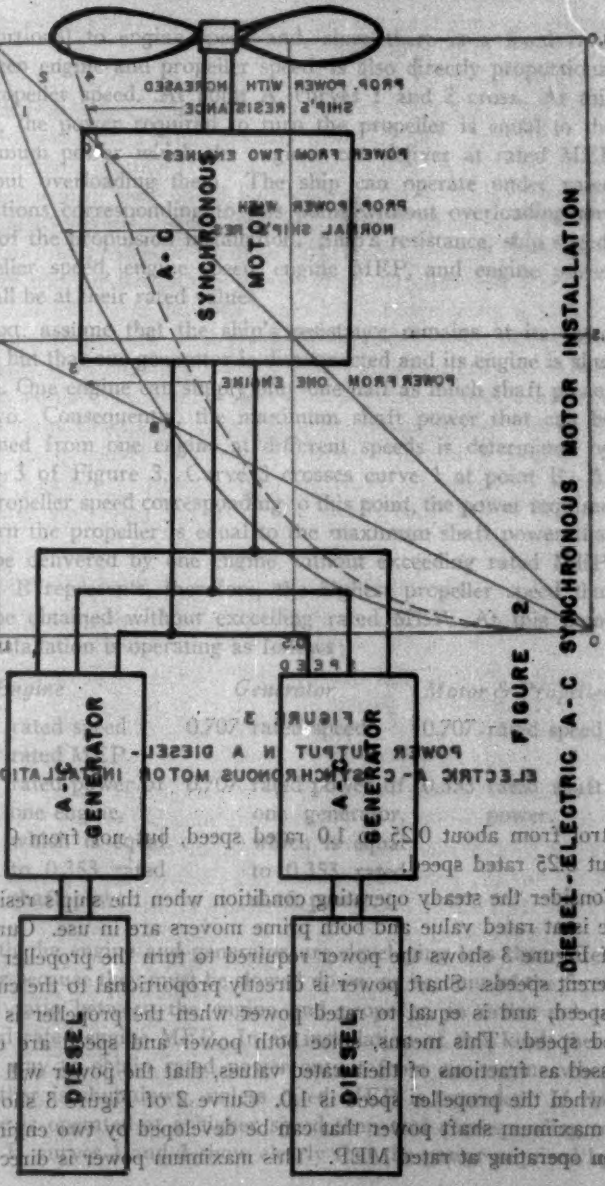

FIGURE 2

FIGURE 3

POWER OUTPUT IN A DIESEL-ELECTRIC A-C SYNCHRONOUS MOTOR INSTALLATION

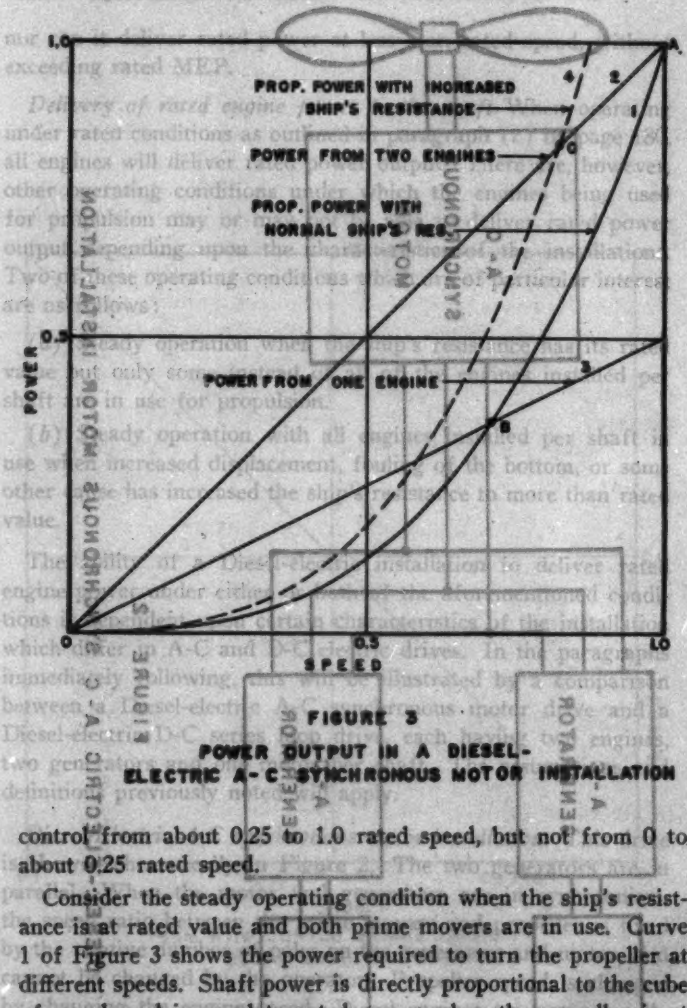

FIGURE 3

POWER OUTPUT IN A DIESEL-ELECTRIC A-C SYNCHRONOUS MOTOR INSTALLATION

control from about 0.25 to 1.0 rated speed, but not from 0 to about 0.25 rated speed.

Consider the steady operating condition when the ship's resistance is at rated value and both prime movers are in use. Curve 1 of Figure 3 shows the power required to turn the propeller at different speeds. Shaft power is directly proportional to the cube of speed, and is equal to rated power when the propeller is at rated speed. This means, since both power and speed are expressed as fractions of their rated values, that the power will be 1.0 when the propeller speed is 1.0. Curve 2 of Figure 3 shows the maximum shaft power that can be developed by two engines when operating at rated MEP. This maximum power is directly

proportional to engine speed and, since there is a fixed ratio between engine and propeller speed, is also directly proportional to propeller speed. At point A, curves 1 and 2 cross. At this point, the power required to turn the propeller is equal to the maximum power which the engines can deliver at rated MEP without overloading them. The ship can operate under rated conditions corresponding to this point without overloading any part of the propulsion installation. Ship's resistance, ship speed, propeller speed, engine speed, engine MEP, and engine power will all be at their rated values.

Next, assume that the ship's resistance remains at its rated value but that one generator is disconnected and its engine is shut down. One engine can supply only one-half as much shaft power as two. Consequently, the maximum shaft power that can be obtained from one engine at different speeds is determined by curve 3 of Figure 3. Curve 3 crosses curve 1 at point B. At the propeller speed corresponding to this point, the power required to turn the propeller is equal to the maximum shaft power that can be delivered by one engine without exceeding rated MEP. Point B represents, therefore, the highest propeller speed that can be obtained without exceeding rated MEP. At this point the installation is operating as follows:

Engine	*Generator*	*Motor & Propeller*
0.707 rated speed	0.707 rated speed	0.707 rated speed
1.0 rated MEP		
0.707 rated power of one engine, which is equal to 0.353 rated shaft power.	0.707 rated power of one generator, which is equal to 0.353 rated shaft power.	0.353 rated shaft power.

Both the engine and generator are developing less than rated power because they must be slowed down, on account of the fixed speed ratio between the engine and propeller, in order not to exceed rated engine MEP. In an installation of this kind, there is no way to obtain rated power output from one engine when the other is shut down, unless rated MEP is exceeded. If the engine is operated at a higher speed than that corresponding to point B, curves 1 and 3 show clearly that the power required by

the propeller is more than one engine can deliver without exceeding rated MEP. This is not permissible.

To consider the effect of a change in ship's resistance, suppose first that the ship's resistance is at rated value and that both engines are in use. The ship will operate under conditions corresponding to point A, as previously described; with all quantities at their rated values. Next, suppose that an increase in displacement, fouling of the bottom, or some other cause except change in ship's speed, increases the ship's resistance to more than rated value. When this happens, more power is required to turn the propeller at a given speed. The curve showing power required by the propeller will now be curve 4 of Figure 3. This curve is not intended to be quantitative but merely to show qualitatively what happens when ship's resistance increases. The exact position of the curve will depend upon how much the ship's resistance increases. Curve 4 intersects curve 2 at point C. Hence, point C determines the speed to which the engines must be reduced in order not to exceed rated engine MEP. At this point, operation will be as follows:

Engines	*Generators*	*Motor & Propeller*
Less than rated speed	Less than rated speed	Less than rated speed
Rated MEP	Less than rated power	Less than rated power
Less than rated power		

The discussion in the preceding three paragraphs shows that with the Diesel-electric A-C synchronous motor drive, it is not possible to obtain rated power output from the prime movers which are in use, either when some are secured and operation maintained with the others, or when all are in use and the ship's resistance increases to more than rated value. Consequently, this type of drive does not possess the features listed as desirable in paragraphs (*e*) and (*g*) on page 177. Hence, because of the characteristics of Diesel engines, as previously discussed, it follows that any Diesel engine drive with a fixed speed ratio transmission, either electrical or mechanical, does not have the features listed as desirable in paragraphs (*e*) and (*g*) on page 177.

Diesel-electric D-C series loop installation. This is the type

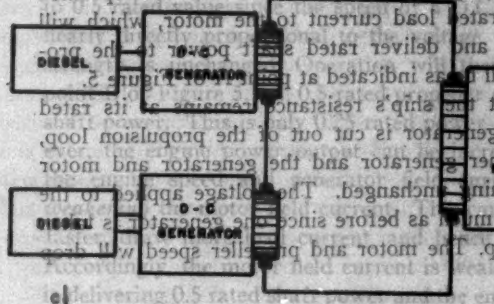

FIGURE 4

DIESEL-ELECTRIC D-C SERIES LOOP INSTALLATION

used in the great majority of Diesel-electric D-C installations in surface ships. It is shown schematically in Figure 4.

The generators and motor are connected in a series loop. The speed ratio between the engines and the propeller can be varied by changing the number of generators used for propulsion, the generator field current, the motor field current, or by any combination of these three changes. With a fixed number of generator sets in use for propulsion, the propeller speed, and hence, ship speed is changed by varying the engine speed, the generator field current, or, within certain limits, the motor field current. From zero to about 0.5 rated propeller speed, the engine is operated at about 0.5 rated engine speed, and propeller speed is changed by increasing the generator field current from zero to rated generator field current. For higher speeds, the generator field current is kept constant at rated value and the propeller speed is changed by varying the engine speed from about 0.5 to 1.0 rated engine speed. This installation gives the feature listed as (*d*) on page 177, that is, continuous operation and smooth control of propeller speed over the entire range ahead and astern.

Assume that the ship's resistance has its rated value and that both generator sets are in use for propulsion. Curve 1 of Figure 5 shows the power needed by the propeller under steady operating conditions at any speed, both propeller speed and shaft power being given as fractions of their rated values. When both engines

are operated at rated speed, their generators will develop rated voltage and supply rated load current to the motor, which will turn at rated speed and deliver rated shaft power to the propeller. Operation will be as indicated at point A of Figure 5.

Next, assume that the ship's resistance remains at its rated value, but that one generator is cut out of the propulsion loop, the speed of the other generator and the generator and motor field currents remaining unchanged. The voltage applied to the motor will be 0.5 as much as before since one generator is taken out of the series loop. The motor and propeller speed will drop

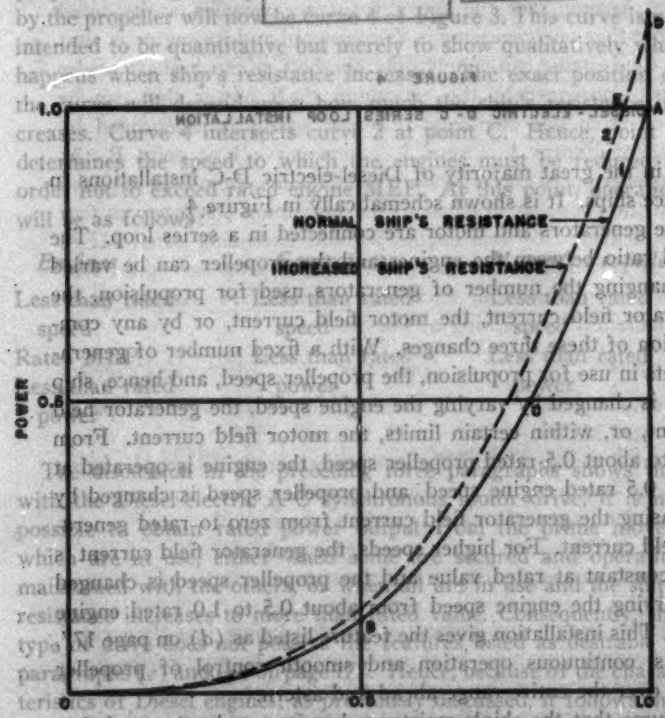

FIGURE 5.
POWER OUTPUT IN A DIESEL-ELECTRIC D-C SERIES LOOP INSTALLATION

to 0.5 rated value since the speed of a D.C. shunt motor is very nearly directly proportional to the voltage when the motor field strength is unchanged. Operation will then be as indicated at point B of Figure 5, i.e., 0.5 rated propeller speed and 0.125 rated shaft power. This is only 0.25 rated power of one engine. However, the engine power output can be increased by maintaining the engine speed and generator field current unchanged, and *weakening* the motor field current. This causes the motor to run faster, draw more load current, and hence deliver more power. Accordingly, the motor field current is weakened until the motor is delivering 0.5 rated shaft power and the engine in use is delivering its rated power output, which occurs when the motor is drawing rated load current. Operation will then be as indicated by point C of Figure 5, where conditions will be as follows:

Engine	*Generator*	*Motor*
Rated speed	Rated speed	0.794 rated speed
Rated MEP	Rated voltage	0.5 rated voltage
Rated power of one engine, which is 0.5 rated shaft power.	Rated load current. Rated power of one generator, which is equal to 0.5 rated shaft power.	Rated load current 0.5 rated shaft power.

Neither the engine nor the generator nor the motor is overloaded. Consequently, no overload capacity is needed in any of these three units in order to obtain rated power from the engine kept in service. The motor, however, must be designed to have certain characteristics apart from overload capacity, which are considered later.

To consider the effect of a change in ship's resistance, suppose first that the ship's resistance is at rated value, that both engines are in use, and that both are running at rated speed and power. Steady operation at rated ship's speed will be as indicated by point A of Figure 5 with the propeller at rated speed and power. Next, suppose that an increase in displacement, fouling of the ship's bottom, or any other cause increases the ship's resistance to more than rated value. The power required to turn the propeller at any given speed will increase and be determined by a new curve, such as Curve 2, for example; the exact amount of the

increase, depending upon how much the resistance is increased. If the propeller speed is kept unchanged, operation will be as indicated by point D of Figure 5 which corresponds to rated propeller speed but more than rated power. This will, of course, overload the engines. The overload on the engines can be removed by *strengthening* the motor field current. This reduces motor and propeller speed, and hence the shaft power. By progressively strengthening the motor field current, the propeller speed and shaft power can be decreased to point E of Figure 5, where operation will be as follows:

Engines	*Generators*	*Motor*
Rated speed	Rated speed	Less than rated speed
Rated MEP	Rated voltage	Rated voltage
Rated power	Rated load current	Rated load current
	Rated power	Rated power

There is now no overload on the engines and generators, since both are operating at rated conditions. The motor, however, must have overload capacity since it is now delivering rated power at less than its rated speed.

Summary of comparison of installations with two engines per shaft. The results of the preceding comparison can be summarized as follows:

(*a*) When the ship's resistance is at its rated value and only one of the two engines is in use for propulsion, the propeller speed, ship speed, and shaft power that can be obtained without overloading the engine in use are as follows:

	Diesel-Electric	
	A-C Synchronous Motor	*Diesel-Electric D-C Series Loop*
Propeller speed	0.707	0.794
Ship speed	0.707	0.794
Shaft power	0.353	0.500

(*b*) When the ship's resistance increases to more than rated value, the rated power output of both engines in the D-C series loop installations can be utilized for propulsion without requiring any overload capacity in the engines. This is not the case in the A-C installation.

(*c*) The reason for these differences is that the D-C installation provides a variable speed ratio transmission between the prime movers and the propeller, while the A-C installation provides a fixed speed ratio transmission. In the D-C installation, the engines can be operated at rated MEP and speed to develop rated power. The propeller speed can then be adjusted independently of engine speed, by varying the speed ratio between engines and propeller, until the propeller is running at exactly the right speed to absorb the rated power output of the engine or engines in use for propulsion. This flexibility is absent in the A-C installation with a fixed speed ratio transmission. In the latter case, when the ship's resistance is at rated value, both engines are in use for propulsion, and both are turning at rated speed, the propeller will also be turning at rated speed, and absorbing rated shaft power. When, however, one engine is cut out, or the ship's resistance increases, the propeller must be slowed down to keep from exceeding the limitation on engine MEP. Since there is a fixed speed ratio between engines and propeller, the engine or engines must be slowed down correspondingly and they will then be operating at less than rated speed and developing less than rated power.

Comparison between Diesel-electric A-C and D-C installations with multiple prime movers per shaft. For installations in which N prime movers are installed per shaft, the propeller speed, ship speed, and shaft power that can be obtained when ship's resistance is at its rated value and n prime movers per shaft are in use for propulsion, are as follows for Diesel-electric D-C series loop and for Diesel-electric A-C synchronous motor installations:

	Diesel-Electric D-C Series Loop	*Diesel-Electric A-C Synchronous Motor*
Propeller speed	Cube root of (n/N)	Square root of (n/N)
Ship speed	Cube root of (n/N)	Square root of (n/N)
Shaft power	n/N	Square root of $(n/N)^2$

These relations are shown graphically in Figure 6. Although this discussion has compared the Diesel-electric D-C series loop drive with Diesel-electric A-C synchronous motor installation, it should be noted that the curves in Figure 6 for the D-C series

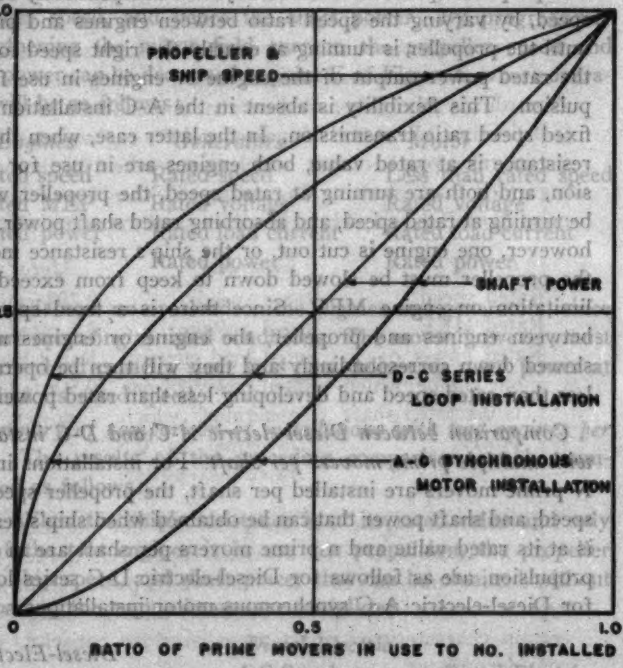

FIGURE 6

COMPARISON OF A-C & D-C INSTALLATIONS WITH MULTIPLE PRIME MOVERS

loop drive apply also for all of the following types of drives with fixed pitch propellers:

Diesel-electric, D-C, series loop
Turbine-electric, D-C, series loop
Diesel-electric, D-C, parallel system
Turbine-electric, D-C, parallel system
Diesel-electric, A-C, with electronic control
Turbine-electric, A-C, with electronic control

The curves for the Diesel-electric A-C synchronous motor installation apply for all of the following types of drives with fixed pitch propellers:

Diesel-electric, A-C, synchronous motor
Diesel, direct drive
Diesel, geared drive
*Turbine-electric, A-C, synchronous motor
*Geared turbine

Figure 6 shows clearly that when only some of the prime movers installed are in use, a higher propeller and ship speed can be obtained with the D-C than with the A-C installation, unless electronic control is employed with the latter. Furthermore, if ship's resistance increases to more than rated value, rated shaft power can still be delivered with the D-C installation but not with the A-C synchronous motor installation.

Motor characteristics needed in a Diesel-electric D-C series loop installation. Previous discussion shows that no overload capacity is needed in the engines or generators in order to obtain rated power output from the units which are in use for propulsion. Hence, there is no need to consider these components. The motor requirements, however, are different. The requirements imposed on the motor by the two operating conditions discussed on page 184 will be considered. These conditions are:

(*a*) When the ship's resistance is at rated value but only some of the prime movers installed are in use for propulsion.

(*b*) When the ship's resistance is above rated value and all of the prime movers installed are in use for propulsion.

* Unless the generators or gears have overload capacity as previously discussed.

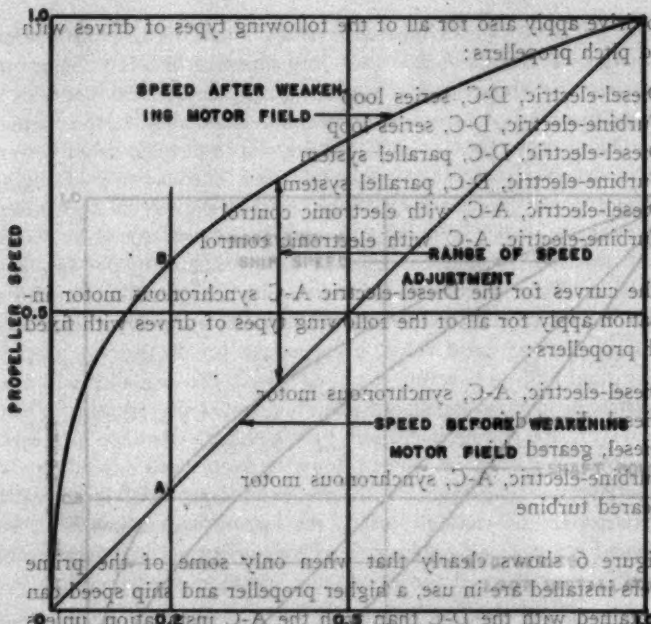

FIGURE 7

RANGE OF MOTOR SPEED ADJUSTMENT IN D-C INSTALLATIONS

In the first of these two cases, it has previously been shown that the motor requires no overload capacity, but the motor must have the following characteristics:

(*a*) The motor must permit speed adjustment by field *weakening* over the range of speed indicated in Figure 7. As an example, consider an installation having five engines per shaft, and assume that all five units are in use delivering rated shaft power at rated propeller speed. If four engines are taken out of service, the ratio n/N decreases from 1 to 0.2 and the motor voltage also decreases from 1.0 to 0.2 rated voltage. Since the motor and propeller speed is proportional to motor voltage if the motor field current

is not changed, the motor and propeller speed also decreases from 1.0 to 0.2 rated speed and the shaft power decreases from 1.0 to .008 rated power. The maximum shaft power available with only one prime mover in use and delivering its rated output is equal to 0.2 rated power, which corresponds to 0.585 rated propeller speed. Hence, the propeller speed which results when four prime movers are taken out of service and the motor field current is not changed, is less than the speed obtainable when only one prime mover is in use and is delivering its rated power output. In order to obtain rated power output from the one prime mover in use, when the others are shut down it is necessary to increase the motor and propeller speed from 0.2 rated speed (point A in Figure 7) to 0.585 rated speed (point B). This range of speed adjustment by motor field weakening can usually be provided in a D-C shunt motor.

(*b*) The motor must be able to carry rated load current at reduced speed. If less than about four engines are installed per shaft, the minimum motor speed for operation at rated load current is high enough so that the ventilation required to remove the heating caused by rated current can probably be supplied by a fan attached to the motor. If more engines are installed per shaft, it may be necessary to supply separate blower motors to produce the ventilation needed when the motor is running at rated current and reduced speed. This can be done without much increase in weight.

In the second of the two cases i.e., when the ship's resistance is above rated value and all of the installed prime movers are in use, overload capacity is needed because the motor must supply rated power at less than rated speed. For tugs, in order to be able to use full power on a dead tow, the motor must be able to deliver rated power at about 0.7 to 0.8 rated motor speed, the exact figure depending upon the particular tug and propeller design. However, this is a larger range of speed adjustment than is needed for combatant vessels, where ability to pull on a dead tow is not an important factor. For these vessels, if the range of speed adjustment by field *strengthening* is enough to permit the motor to deliver rated power from about 0.9 to rated motor speed, the motor and the engines as well will be able to deliver rated power even if the ship's resistance is materially increased

by fouling. This range of speed adjustment by field strengthening can be provided without much increase in the size and weight of a D-C shunt motor.

The conclusion reached from the above discussion is that with the Diesel-electric D-C series loop installation it is possible to deliver the rated power output of each prime mover to the propeller shaft (even when the ship's resistance increases to more than rated value) without requiring the motor to be much bigger and heavier than one which would just deliver rated power at rated speed. As pointed out previously, no overload capacity is needed in either the engines or the generators since all that is required of these is that they be able to deliver rated power at rated speed.

Diesel-electric D-C parallel systems. These are used chiefly in submarines where the necessity of taking power from the battery when operating submerged introduces problems that are absent in installations designed for surface vessels. A few parallel installations are used also in surface vessels for specific applications such as ice breakers. In this type of installation, the generators and motors are connected in parallel, instead of in series as in the series loop installation. The parallel type of installation provides a variable speed ratio transmission between the engines and propeller, smooth control of speed over the entire range, and other operating characteristics similar to those of the series loop installation. No overload capacity is needed in either the engines or the generators in order to obtain rated power output from the engines which are in use for propulsion. The motors require characteristics somewhat different in degree from those of motors for a series loop installation, particularly a wider range of speed control by strengthening the motor field. As a consequence, motors for a parallel system would, in most cases, be somewhat larger and heavier than motors needed for a series loop installation of the same power and having the same number of engines installed per shaft. Furthermore, the control system is more complicated than for the series loop system; a number of contactors capable of interrupting full load current are usually required in the parallel system but not in the series loop; and operation is not as simple with the parallel system because it is necessary to parallel generators. Since the parallel system has

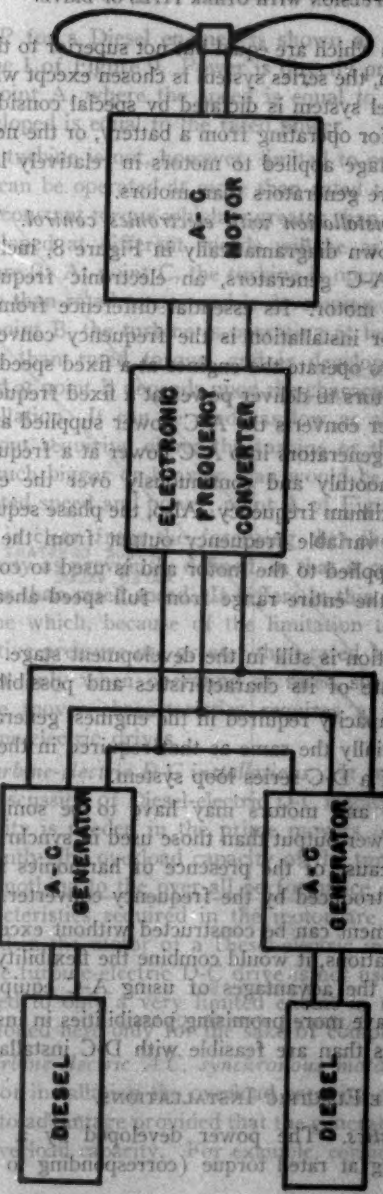

FIGURE 8 DIESEL-ELECTRIC A-C. INSTALLATION WITH ELECTRONIC CONTROL

operating characteristics which are equal but not superior to those of the series loop system, the series system is chosen execpt where the choice of the parallel system is dictated by special considerations, such as the need for operating from a battery, or the necessity of limiting the voltage applied to motors in relatively large installations having more generators than motors.

Diesel-electric A-C installation with electronics control. This type of installation, shown diagramatically in Figure 8, includes Diesel engine driven A-C generators, an electronic frequency converter, and an A-C motor. Its essential difference from the A-C synchronous motor installation is the frequency converter. This makes it possible to operate the engines at a fixed speed and hence allows the generators to deliver power at a fixed frequency. The frequency converter converts the A-C power supplied at the fixed frequency by the generators into A-C power at a frequency that can be varied smoothly and continuously over the entire range from zero to maximum frequency. Also, the phase sequence can be reversed. The variable frequency output from the frequency converter is supplied to the motor and is used to control the motor speed over the entire range from full speed ahead to full speed astern.

This type of installation is still in the development stage. The following is an estimate of its characteristics and possibilities:

(*a*) The overload capacity required in the engines, generators, and motors is substantially the same as that required in the corresponding elements of a D-C series loop system.

(*b*) The generators and motors may have to be somewhat bigger for the same power output than those used in synchronous motor installations because of the presence of harmonics in the current and voltage introduced by the frequency converter.

(*c*) If this arrangement can be constructed without exceeding weight and space limitations, it would combine the flexibility of a D-C installation with the advantages of using A-C equipment.

(*d*) It appears to have more promising possibilities in installations of higher powers than are feasible with D-C installations.

Turbine Electric Installations.

Turbine characteristics. The power developed by a steam turbine when operating at rated torque (corresponding to rated

MEP for a Diesel engine) is shown as a function of speed by curve 1 of Figure 9. Power is directly proportional to speed and at point A, where the speed is equal to rated speed, the power developed is equal to the rated power.

A turbine is not, however, limited to operation at rated torque but can be operated at more than rated torque. When operating at a constant torque which is greater than rated torque, the power developed at different speeds will be as shown by curve 2 of Figure 9. At point C, the turbine is operating at rated speed but more than rated torque and is developing more than rated power. At point B, the turbine is operating at less than rated speed but more than rated torque, and is developing rated power. The speed at point B depends upon the characteristics of the particular installation. It can be made as low as about 0.080 rated speed without requiring either the turbine or the boiler installation to be much bigger or heavier than would be installed for operation at rated speed and power, point A of Figure 9.

It is clear from the foregoing that the turbine has overload capacity as previously defined, in that it can develop rated power at less than rated speed. It differs in this respect from the Diesel engine which, because of the limitation to operation at a mean effective pressure not greater than rated MEP, can develop rated power only when operating at rated speed. This difference in prime mover characteristics requires a brief consideration of turbine-electric drives.

Turbine-electric D-C installations. It follows from the preceding discussion of Diesel-electric D-C installations that *no* overload capacity is needed in the prime movers or the generators. Consequently, the overload capacity of the turbine is not needed and adds nothing to the over-all performance of the installation. The characteristics required in the motor are the same as those required in the motor of a Diesel-electric installation.

The turbine-electric D-C drive is not used in naval vessels and is used to only a very limited extent in merchant vessels. It is mentioned here only for the sake of completeness.

Turbine-electric A.C. synchronous motor installation. In this type of installation the overload capacity of the turbine could be used to advantage provided that the generators have a corresponding overload capacity. For example, consider an installation with

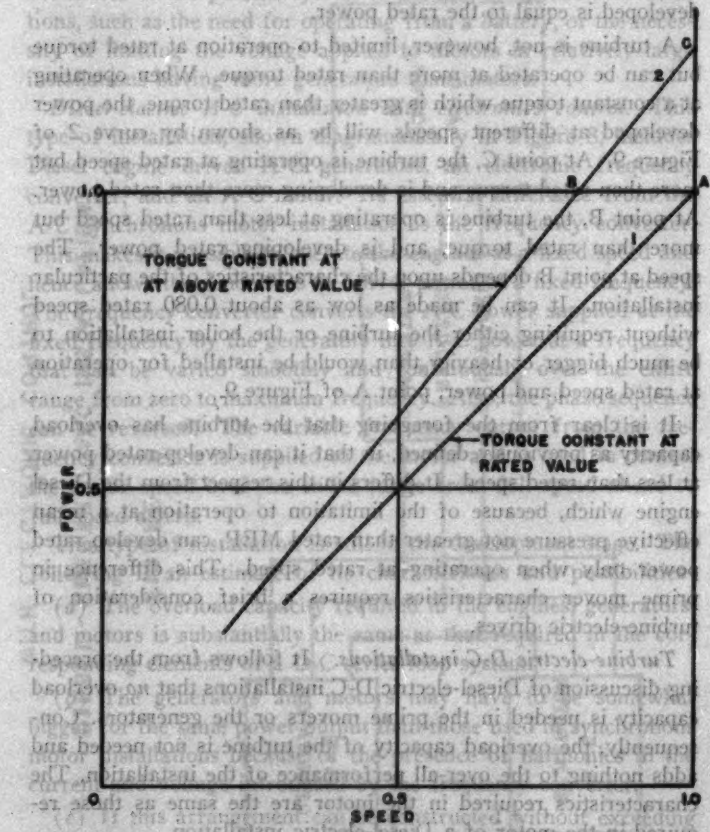

FIGURE 9
TURBINE POWER OUTPUT

two turbine-driven generators per shaft. If the ship's resistance is at rated value and one turbine generator set is shut down, the remaining set can supply its rated power to the propeller, provided that the turbine and generator can develop rated power at 0.794 rated speed. The turbine can accomplish this, or approach it, without having to be much bigger than if built without any overload capacity. However, a generator to deliver rated power at 0.794 rated speed would have to be bigger and heavier than one built without such overload capacity. In usual practice, which is doubtless the soundest one in this case, not enough overload capacity is built into the generator to handle the overload capacity that could be provided in the turbine. Consequently, although the turbine has, or can be built with overload capacity at reduced speeds, this capacity will usually not be usable (at least to its full extent) in turbine-driven A-C synchronous motor installations, because of limitations imposed by the generators. The operating characteristics of the turbine-electric A-C synchronous motor installation will, therefore, be similar to those of the Diesel-electric A-C synchronous motor installation.

Turbine-electric A-C installations with electronic control. This type of installation is similar to the Diesel-electric installation with electronic control which was discussed previously, except that it has turbine instead of Diesel engine-driven A-C generators. The electronic frequency converter provides a variable speed ratio transmission between the turbines and the propeller. With this type of speed transmission, no overload capacity is needed in the prime movers, as pointed out in the previous discussion of D-C installations. Consequently, the overload capacity at reduced speeds that can be built into turbines is not necessary in this type of installation and will not result in better performance than can be obtained from an installation powered by Diesel engines without such overload capacity. The overload capacity required in generators and motors is the same as in the Diesel-electric installation with electronic control.

Gas turbines. While the characteristics of these are not as yet thoroughly established by extensive operating experience, there seems to be little reason to doubt that they will be essentially similar to those of a steam turbine, with one exception. Due to the absence of a vacuum, it will be difficult if not entirely im-

practicable to provide a reversing turbine. For this reason, it seems probable that the use of gas turbines for ship propulsion will be confined to installations with electric drive, a reversing gear, or a controllable and reversible pitch propeller. All of these eliminate the need for a reversing turbine.

Summary of turbine-electric drives. The turbine has overload capacity that is lacking in the Diesel engine, in that it can deliver rated power at less than rated speed, which the Diesel engine cannot do without exceeding its rated mean effective pressure. However:

(*a*) Overload capacity at reduced speeds is not needed in the prime movers in D-C electric drives or A-C electric drives with electronic control, and adds nothing to the performance that can be obtained without it.

(*b*) Overload capacity in the prime movers at reduced speeds cannot be utilized in A-C synchronous motor drives unless the generators are built with corresponding overload capacity. This will usually not be done because of the increased weight and size required.

(*c*) Consequently, the overload capacity of the turbine at reduced speeds as compared with the Diesel engine does not make much practical difference between the two, insofar as their use in electric drive installations is concerned.

Mechanical Drives.

For the purpose of comparison with electric drive installations, the following mechanical drives are considered briefly:

Geared turbine—fixed pitch propeller.
Geared or direct drive Diesel—fixed pitch propeller.
Geared turbine—controllable and reversible pitch propeller.
Geared or direct drive diesel—controllable and reversible pitch propeller.

Geared turbine drive with fixed pitch propeller. While this type of drive could be built with multiple prime movers per shaft, there seems to be no point in doing this since the flexibility of the machinery arrangement would be less than with an electric drive and therefore there would be few advantages to using multiple turbine prime movers. In the usual arrangement of the geared

turbine drive, the different turbines which drive one shaft are several stages of what is essentially only one prime mover rather than a number of separate prime movers. This type of drive has a fixed speed ratio between the turbine and the propeller and is similar in this respect to the turbine-electric A-C drive with synchronous motors.

The operating characteristics of the geared turbine drive are similar to those of the turbine-electric A-C drive with synchronous motors except that:

(*a*) The geared drive gives smooth speed control down to lower speeds than the electric drive, but requires a reversing turbine.

(*b*) The overload capacity of the turbine at reduced speeds can be utilized to advantage if the reduction gear has the same overload capacity. It is probable that this capacity can be built into the gear for decidedly less increase in size and weight than would be required to build the same overload capacity into the generator for an electric drive with synchronous motors. This would give the geared drive somewhat of an advantage since, when the ship's resistance is increased by fouling, the geared drive would be better able to deliver rated power to the shaft at the reduced propeller speed which would be necessary.

Geared or direct drive Diesel with fixed pitch propeller. Either of these has a fixed speed ratio between the engine and the propeller, and the operating characteristics are similar to those of the Diesel-electric A-C drive with synchronous motors, except that a reversible engine or reversing gears are required.

Turbine or Diesel drives with controllable and reversible pitch propeller. The controllable and reversible pitch propeller eliminates the need for a reversing turbine, reversible engines or reversing gears. The feathering of the blades provides the equivalent of uncoupling the shaft from the prime mover. If the pitch adjustment can be made in small steps, this feature (possibly in combination with engine speed control) would give smooth, continuous control of the ship's speed over its entire range. The ability to change propeller pitch makes it possible to utilize the rated power output of all the engines in use (without overloading them), either when the ship's resistance increases to more than rated value or when some of the prime movers are shut down.

Consequently, the drive with a controllable and reversible pitch propeller should have characteristics similar to those of the direct current drive, or the alternating current drive with electronic control and fixed pitch propeller. The controllable and reversible pitch propeller provides the equivalent of a variable speed ratio between the prime movers and the propeller. While this type of drive is not as yet extensively used for ship propulsion, except in small capacities, it gives promise of duplicating the flexible performance characteristics of the direct current electric drive. However, the controllable and reversible pitch propeller drive is not as well adapted as the electric drive to the use of multiple prime movers per shaft.

Summary of Fixed and Variable Speed Ratio Transmissions With Fixed Pitch Propellers.

Summarizing results discussed throughout previous parts of this article, the following conclusions can be drawn regarding these two types of transmission, both with fixed pitch propellers.

(a) *Variable speed ratio transmissions.*

(1) When some units in a multiple prime mover installation are shut down, the rated power output of all left in service can be applied to the propeller shaft without overloading the prime movers in any way.

(2) When all prime movers are in use and the ship's resistance increases to more than rated value, rated power can be applied to the shaft without overloading the prime movers in any way. However, the motor in electric drive installations, or the power transmission in a variable speed ratio mechanical drive, must be capable of delivering rated power at somewhat less than rated speed.

(3) Propeller and ship speed can be varied independently of prime mover speed, and, if the speed ratio is variable in many small steps, smooth speed control is obtained.

(*b*) *Fixed speed ratio transmissions* provide none of the three elements of flexibility listed above for the variable speed ratio transmission. Smooth speed control over the entire range of ship speed can be obtained with a fixed speed ratio transmission only if the prime mover is one capable of smooth speed control throughout its speed range, and rated power output of the prime

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	DIESEL-ELECTRIC				
	Diesel-Electric Direct-Current Series Loop	Diesel-Electric Direct-Current Parallel System	Diesel-Electric Alternating-Current With Synchronous Motor	Diesel-Electric Alternating-Current With Electronic Control	Steam or Gas Electric Direct Series L
1. Does installation provide a speed reduction between prime mover and propeller?	Yes	Yes	Yes	Yes	Yes
2. Is the power transmission between prime mover and propeller a fixed or variable speed ratio transmission?	Variable	Variable	Fixed	Variable	Variable
3. Does installation provide for uncoupling prime mover from propeller?	Yes	Yes	Yes	Yes	Yes
4. Does installation provide full torque astern as well as ahead?	Yes	Yes	Yes	Yes	Yes
5. Does installation provide smooth speed control over entire range of speed both ahead and astern?	Yes	Yes	Smooth speed control between 25% to 100% speed range only.	Yes	Yes
6. Is installation readily adaptable to use of multiple prime movers per shaft?	Yes	Yes	Yes	Yes	Yes
7. In multiple prime mover installations can rated power output be obtained from each prime mover in use when ships resistance has rated value but less than the full number of prime movers installed are in use?	Yes	Yes	No	Yes	Yes
8. What is nature of overload capacity required to obtain performance specified in 7 above?	None, but motors require special characteristics apart from overload capacity.	Motors must have oversize frames to allow sufficient field strengthening to slow motor.	Not applicable	None, but motors require special characteristics apart from overload capacity.	None, but m quire special c istics apart fr load capacity.

TABLE I

TURBINE-ELECTRIC					
Steam or Gas Turbine Electric Direct-Current Series Loop	Steam or Gas Turbine Electric Alternating-Current with Synchronous Motor	Steam or Gas Turbine Electric Alternating-Current with Electronic Control	Geared Steam Turbine with Fixed Pitch Propeller	Geared Steam or Gas Turbine with Controllable Pitch Propeller	Geared Steam or Gas Turbine with Controllable Pitch Propeller
Yes	Yes	Yes	Yes	Yes	Yes
Variable	Fixed	Variable	Fixed	Fixed, but same effect as variable ratio is obtained by varying pitch.	Fixed
Yes	Yes	Yes	No	No, but same effect is obtained by feathering propeller.	Yes, when electro-magnetic coupling is used. Otherwise, No
Yes	Yes	Yes	No	Yes	Yes, when engines are reversed, up to limit of vane gear
Yes	Smooth Speed Control with steam turbine 15–100%, with gas turbine approx. 75 to 100%.	Yes	Yes	Yes	Smooth control between limits of speed range
Yes	Yes	Yes	No	No	Up to limit of shaft rating if hydraulic or magnetic couplings are provided
Yes	No	Yes	No	Yes	No
None, but motors require special characteristics apart from overload capacity.	Not applicable	None, but motors require special characteristics apart from overload capacity.	Not applicable	None	Not applicable

TABLE I

	TURBINE-ELECTRIC					
sel-Electric nating-Current th Electronic Control	Steam or Gas Turbine Electric Direct-Current Series Loop	Steam or Gas Turbine Electric Alternating-Current with Synchronous Motor	Steam or Gas Turbine Electric Alternating-Current with Electronic Control	Geared Steam Turbine with Fixed Pitch Propeller	Geared Steam or Gas Turbine with Controllable Pitch Propeller	
	Yes	Yes	Yes	Yes	Yes	Y
le	Variable	Fixed	Variable	Fixed	Fixed, but same effect as variable ratio is obtained by varying pitch.	F
	Yes	Yes	Yes	No	No, but same effect is obtained by feathering propeller.	Y a p C
	Yes	Yes	Yes	No	Yes	Y a v a v
	Yes	Smooth Speed Control with steam turbine 15–100%, with gas turbine approx. 75 to 100%.	Yes	Yes	Yes	S b a
	Yes	Yes	Yes	No	No	T a if a a
	Yes	No	Yes	No	Yes	N
, but motors re- special character- apart from over- capacity.	None, but motors require special characteristics apart from overload capacity.	Not applicable	None, but motors require special characteristics apart from overload capacity.	Not applicable	None	N

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MECHANICAL DRIVES

Steam or Gas with Controllable Pitch Propeller	Geared Diesel with Fixed Pitch Propeller	Geared Diesel with Controllable Pitch Propeller	Direct Diesel with Fixed Pitch Propeller	Direct Diesel with Controllable Pitch Propeller
	Yes	Yes	No	No
...same effect ...ble ratio is ...by varying	Fixed	Fixed, but same effect as variable ratio is obtained by varying pitch.	Fixed	Fixed, but same effect as variable ratio is obtained by varying pitch.
...same effect is ...by feathering	Yes, when hydraulic or electro-magnetic slip couplings are provided. Otherwise No.	No, but same effect is obtained by feathering propeller.	No, unless a clutch is provided.	No, but same effect is obtained by feathering propeller.
	Yes, when reversing engines are used. When reverse gears are used up to limitation of reverse gears.	Yes	Yes, when reversing engines are used. When reverse gears are used up to limitation of gear used.	Yes
	Smooth speed control between 25 to 100% speed range only.	Yes	Smooth speed control between 25 to 100% speed range only.	Yes
	Up to four units per shaft may be employed if hydraulic or electro-magnetic slip couplings are provided.	Up to four units per shaft may be employed if hydraulic or electro-magnetic slip couplings are provided.	No	No
	No	Yes	No	Yes
	Not applicable	None	Not applicable	None

	DIESEL-ELECTRIC				
	Diesel-Electric Direct-Current Series Loop	Diesel-Electric Direct-Current Parallel System	Diesel-Electric Alternating-Current With Synchronous Motor	Diesel-Electric Alternating-Current With Electronic Control	Steam or Gas T Electric Direct-C Series Loo
9. Can rated power output be obtained from all prime movers in use when ships resistance is increased by fouling, tow or other causes to more than rated value?	Yes	Yes	No	Yes	Yes
10. What special design features are required to obtain performance specified in 9 above?	None in engines or generators. Motors must be able to deliver rated power at less than rated speed.	Motors must have oversize frames to allow sufficient field strengthening to slow motor.	Not applicable	None in engines or generators. Motors must be able to deliver rated power at less than rated speed.	None in engi generators. must be able to rated power than rated spee
11. Can installation be built in such a way that one prime mover can be used to drive two shafts for slow speed operation?	Yes, but not usually provided because several units are normally furnished for each shaft.	Yes	Yes, but not usually provided because several units are normally furnished for each shaft.	Yes	Yes
12. Can reversals from full power ahead to maximum power astern be quickly made?	Yes	Yes	Yes, if dynamic braking is provided.	Yes	Yes
13. Application for which best suited?	For tugs and vessels requiring wide range smooth speed control, roughly suitable for power up to 5000 SHP/Shaft.	For Submarines & for surface vessels having wide variations of loading such as ice breakers.	For medium power range. Roughly for vessels requiring 3000 to 12,000 SHP/Shaft.	Suitable for any type vessel requiring up to 12,000 SHP/Shaft.	Not used in Na stallations.
14. What are principal advantages?	1. High efficiency and long cruising radius. 2. Smooth speed control, item 5 of table. 3. Ability to obtain rated output. Items 7 & 9 of table. 4. Because of items 2 and 3 has excellent operating characteristics.	1. High efficiency and long cruising radius. 2. Smooth speed control, item 5 of table. 3. Ability to obtain rated output. Items 7 & 9 of table. 4. Because of items 2 and 3 has excellent operating characteristics.	1. High efficiency and long cruising radius. 2. Simpler and more rugged electrical equipment as compared to diesel direct current or electronic drives. 3. Lowest cost & lightest weight of any diesel electric drive.	1. High efficiency and long cruising radius. 2. Smooth speed control, item 5 of table. 3. Ability to obtain rated power output. Item 7 & 9 of table.	1. Smooth spee trol. Item 5 o
15. What are principal disadvantages?	1. Direct current equipment is heavier, has higher cost & is more difficult to maintain than alternating current equipment.	1. Requires oversize propulsion motors. 2. Requires complicated control.	1. Does not have wide range speed control or ability to produce rated power from each prime mover under all conditions of operation.	1. Has the added complication of the electronic frequency converter.	1. Low efficienc 2. Greater weig 3. High cost.

TABLE I—Continued

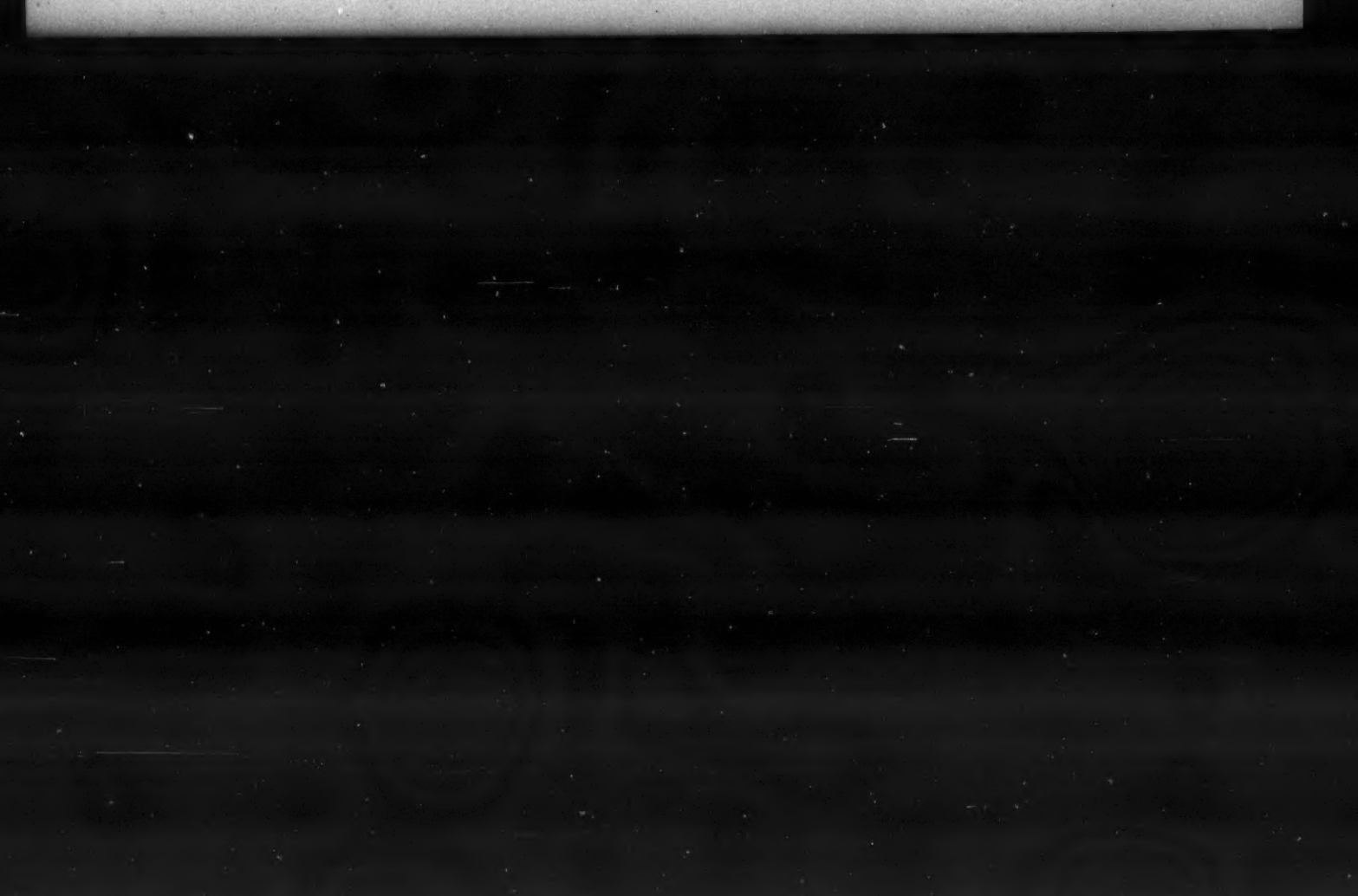
TURBINE-ELECTRIC					
Steam or Gas Turbine Electric Direct-Current Series Loop	Steam or Gas Turbine Electric Alternating-Current with Synchronous Motor	Steam or Gas Turbine Electric Alternating-Current with Electronic Control	Geared Steam Turbine with Fixed Pitch Propeller	Geared Steam or Gas Turbine with Controllable Pitch Propeller	Geared D... Fixed ... Prop...
Yes	No	Yes	Yes to a limited extent	Yes	No
None in engines or generators. Motors must be able to deliver rated power at less than rated speed.	Not applicable	None in engines or generators. Motors must be able to deliver rated power at less than rated speed.	Required overload capacity usually inherent in normal design.	None	Not applic...
Yes	Yes	Yes	No	No	No
Yes	Yes	Yes	Backing power up to rating of astern turbine can be quickly applied.	Yes	No
Not used in Naval installations.	Suitable for any steam driven vessel requiring up to maximum power installed in any ship.	Suitable for steam or gas turbine vessel of any power up to capacity of available electronic tubes.	Suitable for any steam vessel of any power.	Suitable for any type steam driven vessel for which required size variable pitch propeller is available.	Any diesel ... sel.
1. Smooth speed control. Item 5 of table.	1. Simplicity of operation. 2. Ease of maintenance. 3. Good reliability.	1. Smooth speed control. Item 5 of table. 2. Ability to obtain rated power output. Items 7 & 9 of table.	1. Simplicity. 2. Reliability. 3. Highest efficiency of any power plant at rated power.	1. Smooth speed control, item 5 of table. 2. Ability to obtain rated power output items 7 & 9 of table.	1. High ef... long cru...
1. Low efficiency. 2. Greater weight. 3. High cost.	1. Does not have wide range speed control or ability to produce rated power from each prime mover under all conditions of operation.	1. Has the added complication of the electronic frequency converter.	1. Requires separate reversing turbines.	1. Propeller efficiency is lowered as pitch is reduced from rated value. 2. Not fully developed for high power.	1. Does ... range ... speed ... ability ... rated ... each ... under ... of ope...

TABLE I—Continued

		TURBINE-ELECTRIC				
ectric -Current hronous or	Diesel-Electric Alternating-Current With Electronic Control	Steam or Gas Turbine Electric Direct-Current Series Loop	Steam or Gas Turbine Electric Alternating-Current with Synchronous Motor	Steam or Gas Turbine Electric Alternating-Current with Electronic Control	Geared Steam Turbine with Fixed Pitch Propeller	Geared Steam or Gas Turbine with Controllable Pitch Propeller
	Yes	Yes	No	Yes	Yes to a limited extent	Yes
le	None in engines or generators. Motors must be able to deliver rated power at less than rated speed.	None in engines or generators. Motors must be able to deliver rated power at less than rated speed.	Not applicable	None in engines or generators. Motors must be able to deliver rated power at less than rated speed.	Required overload capacity usually inherent in normal design.	None
t usually ssed ser- normally each shaft.	Yes	Yes	Yes	Yes	No	No
mic brak- ed.	Yes	Yes	Yes	Yes	Backing power up to rating of astern turbine can be quickly applied.	Yes
m power ghly for ring 8000 HP/Shaft.	Suitable for any type vessel requiring up to 12,000 SHP/Shaft.	Not used in Naval installations.	Suitable for any steam driven vessel requiring up to maximum power installed in any ship.	Suitable for steam or gas turbine vessel of any power up to capacity of available electronic tubes.	Suitable for any steam vessel of any power.	Suitable for any type steam driven vessel for which required size variable pitch propeller is available.
iency and ing radius. and more electrical t as com- iesel direct r electronic nt & light- ht of any ctric drive.	1. High efficiency and long cruising radius. 2. Smooth speed control, item 5 of table. 3. Ability to obtain rated power output. Item 7 & 9 of table.	1. Smooth speed control. Item 5 of table.	1. Simplicity of operation. 2. Ease of maintenance. 3. Good reliability.	1. Smooth speed control. Item 5 of table. 2. Ability to obtain rated power output. Item 7 & 9 of table.	1. Simplicity. 2. Reliability. 3. Highest efficiency of any steam plant at rated power.	1. Smooth speed control, item 5 of table. 2. Ability to obtain rated power output items 7 & 9 of table.
have wide ed control to produce ower from ime mover conditions tion.	1. Has the added complication of the electronic frequency converter.	1. Low efficiency. 2. Greater weight. 3. High cost.	1. Does not have wide range speed control or ability to produce rated power from each prime mover under all conditions of operation.	1. Has the added complication of the electronic frequency converter.	1. Requires separate reversing turbines.	1. Propeller efficiency is lowered as pitch is reduced from rated value. 2. Not fully developed for high power.

MECHANICAL DRIVES

Steam or Gas with Controllable Pitch Propeller	Geared Diesel with Fixed Pitch Propeller	Geared Diesel with Controllable Pitch Propeller	Direct Diesel with Fixed Pitch Propeller	Direct Diesel with Controllable Pitch Propeller
	No	Yes	No	Yes
	Not applicable	None	Not applicable	None
	No	No	No	No
	No	Yes	No, except on small units or with reverse gears.	Yes
for any type driven vessel for required size pitch propeller able.	Any diesel driven vessel.	Any diesel driven vessel for which required size variable pitch propeller is available.	Small auxiliary coastal or harbor vessels.	Small auxiliary coastal or harbor vessels.
oth speed control item 5 of table. lity to obtain l power output s 7 & 9 of table.	1. High efficiency and long cruising radius.	1. High efficiency and long cruising radius. 2. Smooth speed control, item 5 of table. 3. Ability to obtain rated power output, items 7 & 9 of table.	1. High efficiency and long cruising radius.	1. High efficiency and long cruising radius. 2. Smooth speed control, item 5 of table. 3. Ability to obtain rated power output, items 7 & 9 of table.
eller efficiency wered as pitch is ced from rated s. fully developed igh power.	1. Does not have full range of smooth speed control or ability to produce rated power from each prime mover under all conditions of operation.	1. Propeller efficiency is lowered as pitch is reduced from rated value.	1. Heavy weight. 2. Limited to one prime mover per propeller. 3. Does not have full range of smooth speed control or ability to produce rated power from each prime mover under all conditions of operation.	1. Propeller efficiency is lowered as pitch is reduced from rated value. 2. Limited to one prime mover per propeller. 3. Heavy weight.



movers can be delivered to the propeller only when all are in use and the ships resistance is at its rated value. The operating characteristics of a fixed speed ratio transmission are, therefore, inferior to those of a variable speed ratio transmission. The fixed speed ratio transmission is, however, usually simpler than a variable speed ratio transmission.

Table of Comparison.

Table I permits a ready comparison to be made between the salient characteristics of different types of drives for ship propulsion. This table does not give quantitative estimates of efficiency, weight, space, etc. since these require detailed consideration for each specific case, but it does give some idea of the probable direction of differences in these respects. Its principal value lies in the overall view of the characteristics of propulsion installations which it provides: a view which is necessary as a starting point for more detailed investigations. No one type of propulsion installation is superior to the others in all respects. The table makes it possible to see at a glance what desirable features are possessed by the different types of installation, and what is necessary in order to obtain these features.

NOTES.

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—Pacific Marine Review, January, 1947.

ATOMIC ENERGY AND ITS APPLICATIONS.
—The Institute of Fuel, December, 1946.

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—Heating, Piping and Air Conditioning, March, 1946.

RUSTING CHARACTERISTICS OF TURBINE LUBRICATING OILS.
—Mechanical Engineering, October, 1946.

ENGINEERING LESSONS AND GAINS OF THE RECENT YEARS.
—Westinghouse Engineer, January, 1947.

TECHNICAL PROGRESS IN MARINE ENGINEERING DURING 1946.

This interesting summary of the progress made in Great Britain over the past year in Marine Engineering is reprinted from the January 1947 issue of the "Shipbuilding and Marine-Engine Builder." The article does not cover the field in detail, but will serve as a guide to further reading for those who are interested in British developments along a particular line. For those who are interested in the broad picture it is excellent reading.

INTRODUCTION.

Certain leading developments always stand out when the preparation of this annual survey has to be considered. What are they, so far as 1946 is concerned? Probably, no two marine engineers would give the same emphasis in replying to this question, but, in our view, the following are the features which, in broad outline, provide the framework within which a more detailed picture may be presented: the ousting of coal as a maritime fuel; increasing practical interest in gas turbines; the successful redivivus of low-grade boiler-quality fuel oil as a fuel for Diesel engines; the progress made in connection with geared steam turbines and water-tube boilers for tonnage which, before the war, would, in all probability, have been equipped with Diesel engines; and the completion of several important British-built turbo-electric vessels.

From a national, rather than a technical, point of view the entry into normal transatlantic service of the Cunard White Star liner *Queen Elisabeth* cannot be overlooked in this survey, for she is a "new" ship so far as the technical Press is concerned. Broadly similar to her famous sister, the *Queen Mary*, in so far as main-machinery characteristics are concerned, the *Queen Elisabeth* is noteworthy in that she has no more than 12 Yarrow water-tube boilers for her normal service power of 160,000 S.H.P. It is certain, moreover, that these large boilers could provide steam for a considerably greater output than that mentioned, and which is sufficient to give a service speed of about 28½ knots. Service experience with these boilers—as with the main and auxiliary machinery—has been most satisfactory, and they have been further improved by the introduction of external circulating pipes (about 6 inches in diameter) which connect the upper and lower drums.

In regard to the main turbines, the same interesting four-pinion, four-casing layout, with a form of nodal drive, which proved so successful in the earlier *Queen*, has been adopted in the more recent ship; and performance records certainly justify the choice. Both ships played a strenuous part during the war, and their machinery and boilers were fully equal to the demands made on them.

It is interesting to conjecture what might have been the behavior of some of the German liners of the immediate pre-war era had they been called upon to undertake such arduous duties—and with a minimum of attention. It is, in our view, improbable that their advanced turbine machinery and ultra-modern boiler plants would have given such a good account of themselves; experience with both naval and mercantile vessels suggests this, and it seems certain that the overall operational economy, allowing for repair and maintenance charges, would scarcely have been so favorable. Though the *Queens* may appear conventional to Continental marine engineers—and even perhaps too conservative—they have clearly been built to a machinery specification which, for onerous service and sustained reliability, is admirable.

Coal as a fuel for ships has become a mainly academic interest to marine engineers—and a luxury for shipowners. Costing today about 65s. 0d. per ton in the Port of London, it has ceased to be a "paying proposition"; boiler oil can be had in the same area for about 77s. 9d. per ton—figures which make it superfluous to seek technical explanations for the present popularity of oil-burning ships with erstwhile coal-using owners. With even greater emphasis, the present-day popularity of the motorship draws attention to the unhappy, uneasy position of our coal industry *vis-à-vis* shipping. How can an owner of coasting ships, for instance, contemplate placing orders for coal-burning ves-

sels, relatively attractive in first cost as they may be? The latest—and largest—"flat-iron" collier, designed for service between North-East ports and the Thames, has been equipped with Diesel propelling machinery for very sound reasons; and it seems unlikely that coal-using steam installations will reappear for this service when more vessels of the type are ordered.

Practical interest in the gas turbine has already been displayed by one British shipowning company, for, in 1946, it was announced that the Anglo-Saxon Petroleum Co., Ltd., had ordered a 1200-S.H.P. set for installation in a Diesel-electric oil-tank ship now being built on the Tyne. The vessel, as originally conceived, is of considerable technical interest, for she is to be propelled by four Sulzer four-stroke cycle Diesel engines directly coupled to generators which will supply electric energy to a single propelling motor. The engines are to be pressure-charged on the Buchi system, and it is worthy of note that this will be the first large ship to be propelled by Sulzer four-stroke cycle engines. The ultimate intention, it is inderstood, is to replace one of the Sulzer-engine sets by a gas turbine and generator, for which the British Thomson-Houston Co., Ltd., are to be responsible. In this way, a useful amount of sea experience should be accumulated, and, in the event of difficulty being experienced, the comparatively-high normal speed of the vessel will suffer only slight reduction. This is a development concerning which further news will be awaited with interest, perhaps even impatience, by all who believe—as does this journal—that the gas turbine has an important future in the sphere of ship propulsion.

Other developments in connection with gas turbines are envisaged by the Anglo-Saxon technical experts, and their two-unit turbo-electric installations will provide them with a safe basis for a more ambitious experiment than that just referred to. It is planned to substitute for one of the steam turbo-alternator sets in a *Helicina*-class ship, a gas turbine of equivalent net output—assuming, of course, that the smaller trial unit in the Diesel-electric ship proves successful. This more ambitious scheme will be watched with great interest, as the plant will have an output capacity likely to appeal to many owners. Here, again, if for any reason the gas turbine should have to be shut down, the vessel will be able to proceed on the single steam turbine-driven alternator—a comforting consideration which will doubtless accelerate the experiment.

An interesting—if brief—allusion to marine gas turbines was made by Lord Aberconway at the recent launch of the Cunard White Star liner *Media* from the Clydebank shipyard of Messrs. John Brown & Co., Ltd. Two sets of turbines are now being built in their shops and a third unit is on the d awing board. The completion of the first of these experimental sets (concerning which no information has so far been released) will be awaited with keen anticipation. Meanwhile, developments in Switzerland are proceeding, if more slowly, on the marine side. Messrs. Brown, Boveri & Co., Ltd., at one time had high hope of installing a gas turbine for main propulsion in a "Liberty" ship, but the project was eventually abandoned. The Swiss firm have, however, completed a number of stationary gas turbines during the past year, including some of considerable size, and they have put forward a number of marine proposals. Having regard to their unique experience in connection with the gas turbine and their sound marine engineering reputation, one may hazard the guess that they will not have to wait much longer for their first marine order. Like many British marine engineers, they favor the geared layout rather than the gas turbine-electric system; and adjustable-pitch propellers figure in most of their proposals.

The most serious demerit of the gas turbine for marine duty is the large size of the associated air heaters and recuperators, and the considerable amount of large-diameter pipe work involved. The latter feature, it seems, will be most difficult to improve, but we may hopefully look for rapid advances in the design of air heaters and recuperators. Indeed, progress *must* be made here if gas turbines are to attract owners to the extent which their technical potentialities promise. Messrs. Sulzer Brothers are one of the many firms engaged on the whole broad subject, and, in their development work, this

question of the excessive size of the ancillary units is being kept well to the fore. A good thermal efficiency is claimed for their design—superior to the best marine turbine practice at all loads, they assert. A 7000-S.H.P. installation is almost ready for test, and we shall, no doubt, be in a position to describe it in due course. Meanwhile, this progressive firm are continuing to improve their standard range of marine and other Diesel engines, and to develop their "power-gas" and high-supercharge processes, which promise interesting results.

Other British companies have been mentioned during the past year in connection with marine gas turbines; and it is noteworthy that not a few of them have substantial interests in the construction of turbo-generators for shore duties. Of these firms, only Messrs. C. A. Parsons & Co., Ltd., reached the point at which they permitted details of an actual experimental set to be released. The Parsons open-cycle gas-turbine plant of 500 (available) horsepower is a straightforward machine which has now done a considerable amount of running. According to present indications, it seems unlikely that the design will be developed for marine work—although the fact must not be overlooked that Messrs. C. A. Parsons & Company supplied the turbo-electric machinery for the new Canadian Pacific *Beaver*-class vessels.

Pametrada.

No doubt, the experience gained in operating this gas-turbine plant will be available for investigation by the Parsons and Marine Engineering Turbine Research and Development Association (Pametrada), now in active operation at Wallsend under the immediate direction of Dr. T. W. F. Brown. The Association, of course, have their own plans for marine gas turbines, though the form their design will take cannot be discussed at present; but, with the ample resources and growing testing facilities at their disposal, Pametrada should be able to offer to sponsors a sound design much more quickly than would otherwise be possible. The Association will also, of course, confer undoubted benefits on member firms in regard to steam turbines of improved design and performance.

Among the items of the research program carried out largely on the premises of Messrs. C. A. Parsons and Co., Ltd., while the Association were awaiting the completion of their own buildings and the acquisition of research apparatus, are the following:—

A stress analysis, by photo-elastic means, of certain types of straddle-root forms of turbine blading was carried out, in conjunction with tensile tests on actual materials similar to those used in the blades and rotors, to determine the best proportions of the bearing surfaces of the roots.

Tests on a research turbine incorporating reaction blading having a bull-nosed entry were carried out. These tests covered both end-tightened and radial-clearance blading. Steaming tests, corresponding to varying ratios of blade speed to steam speed, enabled efficiency figures to be determined.

A spray-tester rig of Pametrada design was first erected and used in their research building. Experiments to determine the quality of the spray from a variety of nozzles supplied with fuel oil of varying grades were carried out, and the Association have thereby added considerably to their design data for gas-turbine sprayers using heavy fuel oil.

Preliminary experiments have been made on the strength of the fastenings of built-up diaphragms, and these are to be amplified by a further series of experiments in the near future.

Equipment for the study of vibration phenomena has been developed, the latest instruments and electronic techniques being incorporated.

On the metallurgical side, there has been close liaison with various forges producing high-temperature materials, and data regarding the properties of materials to be used in marine gas-turbine design have been accumulated. The question of steam-turbine materials has also been studied during 1946.

Turbo-Electric Installations.

In planning this survey, we asked a number of marine engineers to state which, in their opinion, were the most interesting and significant machinery

installations of the past year, and, without exception, those of the new *Beaver*-class cargo liners of the Canadian Pacific fleet were singled out for special comment. Many readers will, no doubt, concur in this assessment. A reheat cycle incorporating a single turbo-alternator unit of considerable size, and using steam at a pressure of 850 pounds per square inch and a temperature of 850 degrees F., is somewhat exceptional, to say the least; but the technical boldness of the designers of the *Beaverdell* and her sister ships does not end there. Steam, it may be recalled, is supplied by a single Babcock-Johnson boiler, and this unit incorporates reheating as well as superheating sections. A Howden-Johnson combined fire-tube and water-tube auxiliary boiler generates saturated steam for domestic services, make-up feed, and turbine-gland and fuel-oil heating duties. Not the least interesting aspect of the installation is the manner in which one of the comparatively large Allen Diesel-generating sets is coupled in tandem to a Parsons alternator and an Allen D.C. machine, so that, in the event of the main turbo-alternator being out of commission, the Allen-Parsons Diesel-alternator set can supply sufficient energy to the propelling motor to keep steerage way on the vessel; a speed of about 6½ knots was obtained on trial with this arrangement.

The new *Beaver* ships have performed well in service and have shown very good fuel economy. Their machinery installations and the performance of the latter formed the subject of a recent paper presented by Mr. A. W. Davis, B.Sc., to the North-East Coast Institution of Engineers and Shipbuilders, and all who seek further information on a highly interesting development in marine machinery are urged to study it; they will find in it much to stimulate thought.

Another interesting turbo-electric installation completed in this country in recent months is that of the oil-tank ship *Helicina*. The B.T.H. main turbo-alternator equipment of this vessel represents a more conventional solution of the propulsion problem for a large high-powered single-screw ship than does that of the *Beaver* vessels. Her owners (the Anglo-Saxon Petroleum Co., Ltd.) prefer to have two turbo-alternators, and for such an exacting service, the choice has much to commend it. Moreover, if the position in regard to freight rates does not justify the high speed of which the vessel is capable, one turbo-alternator can be shut down and a more economical (but still comparatively high) speed maintained, with one set operating at optimum efficiency. The boilers in the *Helicina* do not incorporate reheating units, as do those in the *Beaver* ships, but it is planned to employ a heavy asphaltic-base fuel oil as soon as supplies are such as to make this interesting experiment possible.

In connection with this development, the Anglo-Saxon Company sponsored experiments (conducted at the works of Messrs. Swinney Brothers, Ltd., Morpeth), designed to investigate the burning of low-grade asphalt-base fuel oil under marine boilers. While this may not be such a difficult undertaking as that presented by the *Auricula* experiment—in which a similar problem was tackled in connection with the use of low-grade fuel in a Diesel engine—the utilization of a highly-viscous petroleum residue as boiler fuel involves a number of practical difficulties which have been solved to the owners' satisfaction. It had been intended to operate the recently completed *Helicina* on such fuel oil, but, at the time of her trials, supplies were not available in this country. In due course, the Anglo-Saxon Petroleum Co., Ltd., will, no doubt, give an account of their experience with this heavier fuel oil, the satisfactory employment of which under marine boilers should represent an important practical and economic development.

Geared Steam Turbines.

The two-casing steam-turbine installation, with double-reduction gearing, has made notable headway in Britain during recent years, and further orders for such machinery were placed during the period under review. The modern form of double-reduction gearing constitutes a reliable piece of mechanism which has effectively lived down the evil reputation the principle earned for itself after the first world war. Much has been learned concerning the need for accuracy in gear-cutting and gearing design generally, and investigation

and improvement are not standing still, despite the satisfactory stage which has now been reached.

At one time, some marine engineers expressed doubts as to the wisdom of adopting astern turbines in one casing only, but service experience has shown the practice to be satisfactory in numerous instances. Clearly, there is no objection to the incorporation of astern blading in both casings, if the particular conditions call for larger astern power, and such sets are, in fact, being built.

With the increasing steam temperatures envisaged in the search for still better performances from geared-turbine installations, astern elements are bound, almost inevitably, to become an increasing worry to the designer. Recent information concerning their latest designs shows that, in the immediate pre-war period, German designers were alive to the difficulties. Specialists in this country are likely to offer better designs which should make for high reliability in the largest geared-turbine installations having astern sections taking steam at temperatures hitherto considered more suitable for turbo-electric plants.

An alternative solution to the reversing problem in its relationship to modern steam conditions is the adoption of mechanical reversing gear. That this is not an impracticable proposal was shown in the paper by Mr. Davis, to which reference has already been made. The author briefly described such a scheme, now in course of development, and the drawing which accompanied his exposition showed it to be not only ingenious, but also, so far as could be judged, practical. A large-scale experiment would afford confirmation of its value at sea, and it is hoped that a suitable opportunity may be found to incorporate the system in a ship. Clearly, the scheme has great potentialities for use in association with gas turbines, as well as with steam turbines, and this fact will no doubt encourage its sponsors to press forward vigorously with its development. It is no exaggeration to say that this problem of astern power is among the most important of the moment.

Reciprocating Steam Engines.

Reference has been made in previous annual surveys to the Gotaverken quadruple-expansion marine steam engine, in which noteworthy economy in steam consumption is achieved without radical departure from conventionality in the mechanical sense. The design does, however, reveal keen appreciation of the factors conducive to good steam consumption in a reciprocating engine of moderate size, and very satisfactory results have been achieved without recourse to refinements which entail high manufacturing cost or undue complication. The present survey is scarcely the place to discuss the general features of the design, but the latest development—perhaps an inevitable one—is the association with this engine of the Gotaverken steam turbo-compressor.

One or two such installations have been built during the past year, and, not unexpectedly, the results have been excellent. With coal as fuel, and with reheater and turbo-compressor in operation, such an engine, of 1500 I.H.P., has returned an all-purpose fuel consumption of 0.805 pound per I.H.P. per hour—a remarkably fine performance. At the present juncture, when oil is generally considered to be the only practicable marine fuel, it is of interest to note that this performance represents a specific consumption of 0.625 pound of oil per S.H.P. The moderate steam pressures and temperatures adopted for these engines are such as can be obtained with Scotch boilers, and installations of this design would appear to have considerable interest for the owner of medium-size and moderate-power tonnage, as an alternative to Diesel machinery.

It would be interesting to see what results could be obtained from an installation of this kind, supplemented by combustion-chamber superheaters capable of giving a steam temperature in the neighborhood of 750 degrees F., instead of the moderate figure of about 600 degrees F. employed in the vessels for which results have just been quoted.

Marine Diesel Engines.

On more than one occasion in these annual surveys we have commented upon the stage of stabilization which large marine oil-engine design has reached, and in this connection it is interesting to note the considerable number of firms in this country who now hold a license in respect of the Doxford opposed-piston engine. Among them are such well-known companies as the North Eastern Marine Engineering Co. (1938), Ltd., the Wallsend Slipway & Engineering Co., Ltd., Messrs. Swan, Hunter & Wigham Richardson, Ltd., and Messrs. R. & W. Hawthorn, Leslie & Co., Ltd.; while, overseas, the Wilton-Fijenoord organization are now in a position to offer machinery of the Doxford type, in addition to engines of other designs with which their name has long been associated. The Canadian-Vickers arrangement represents another overseas license. In view of the technical and practical success of the Doxford engine—the company recently announced that no fewer than 163 opposed-piston marine oil engines of the Doxford type were under construction in their own works and those of their licensees—this extension of licensing arrangement not only represents sound policy for this country, but is a development which will be welcomed by many shipowners and superintendent engineers.

Reference to the building of marine oil engines under license recalls the fact that Messrs. William Gray & Co., Ltd., West Hartlepool, last year acquired a license enabling them to build marine Diesel engines of the Polar design. This company have not hitherto built Diesel machinery, and their decision to take up the manufacture of a popular engine, with long experience behind it, is one which has much to commend it. Any endeavor to enter the market with a completely new marine oil-engine design at the present juncture would probably represent questionable commercial policy, irrespective of the merits or special characteristics of the design; and, in any case, to manufacture under license is certainly a sound and practicable course, both economically and technically, for a newcomer today, however well known.

Messrs. Gray are to build one type of Polar engine, with one size of cylinder, corresponding to the latest and larger version of this well-known engine, which has been developed in Stockholm during the last few years. Known as the MT type, it is rated to develop 400 B.H.P. per cylinder at 250 R.P.M.—a very useful size for direct-drive installations of medium power, or for those in which indirect propulsion (with multiple engines and reduction gearing) are considered appropriate. In this particular version of the Polar engine, the Atlas Diesel Company's latest fuel-injection arrangements, which make for a very smooth-running and quiet engine, are incorporated. Scavenging air is supplied by a compact fan-type blower (of fairly high speed) in place of the reciprocating pump formerly employed.

The latest Sulzer crosshead-type marine Diesel engine, embodying, as it does, a number of improvements and refinements in design, makes it particularly attractive for cargo-ship and intermediate-liner propulsion. Standardization has been carefully considered in the development of the range. Although engines of the type have been built in Switzerland by Messrs. Sulzer Brothers in recent months, the first British-built example has only recently been completed by Messrs. Alexander Stephen & Sons, Ltd., Linthouse, Govan, Glasgow. An improved design of cylinder cover, better cooling arrangements around the combustion-chamber end of the liner, modified framing, changes in crankshaft design, a new piston design and a different arrangement of crosshead and small-end bearing are some of the changes which make this engine even better than the Sulzer single-acting, two-stroke cycle unit, which has given such good service in many vessels built before the war. Messrs. Sulzer Brothers favor a separate scavenging pump for each cylinder, the pumps being driven from the appropriate main crosshead. In the Stephen-built version, however, the normal, single, reciprocating pump at the end of the engine has been retained in the machinery recently completed.

One of the most significant technical developments of the year was marked by the placing in service of the Anglo-Saxon oil-tank ship *Auricula*. To all intents and purposes a standard 12,000-ton deadweight vessel of this com-

pany's extensive fleet, the *Auricula* was selected for an important full-scale experiment in fuel technique, initiated to examine the practical problems associated with the possible use of heavy so-called boiler oil as fuel for the main Diesel-engine cylinders. Service experience has confirmed the practical success of the venture. The merit of the development, as we see it, is that such interesting results should have been achieved with what is, virtually, a standard Hawthorn-Werkspoor Diesel engine, with under-piston pressure charging. The experiments which preceded the decision to use this heavy type of fuel oil in the *Auricula* were initiated about three years ago, when a single-cylinder engine, of the same cylinder dimensions and general design as the main engine of the *Auricula* (and many other vessels of the Anglo-Saxon fleet), was set to work on comparatively heavy, low-grade fuel oil in the St. Peter's Works of Messrs. R. & W. Hawthorn, Leslie & Co., Ltd., Newcastle-on-Tyne.

The financing of these investigations and the experimental program generally were the responsibility of the Anglo-Saxon Petroleum Co., Ltd. Before any attempt was made to burn the heavier fuel, the engine was run continuously for seven days on pool marine Diesel fuel, so that a complete record of its performance on ordinary Diesel fuel might be available to provide a basis of comparison for the performance with heavier-grade fuel. The next step was to employ a mixture of normal Diesel oil and heavier Admiralty-type fuel oil, and this was successfully accomplished with only minor incidental difficulties. Ultimately, it was found possible to operate the engine on Admiralty fuel oil alone after various small, but important, adjustments had been made to obtain a combustion efficiency equal to that achieved with Diesel oil.

The completion of these experiments encouraged those responsible to go even further, and the next step was to attempt to burn really heavy Venezuelan boiler fuel oil, having a maximum viscosity of 1500 seconds Redwood I. at 100 degrees F. The first tests were made with a mixture consisting of 10 per cent of this fuel and 90 per cent of marine Diesel oil, subsequent experiments having been made with progressively increased proportions of the heavy fuel oil, which the experimenters dubbed Ordoil. Eventually, it was found possible to run the engine on Ordoil only, once it had been started and warmed through on Diesel fuel. Much was learned from these experiments, but, naturally, they were not of sufficiently long duration to establish with any degree of certainty the amount of cylinder-liner and piston-ring wear encountered with the inferior fuel. Nevertheless, the owners, encouraged by the experiments on the single-cylinder unit, decided to proceed with an installation for a large vessel, and the trials and subsequent service performance of the *Auricula* (built and engined by Messrs. R. & W. Hawthorn, Leslie & Co., Ltd.) have demonstrated that it is eminently practicable for an engine of this type and size to operate with what is virtually a heavy grade of fuel oil, hitherto considered suitable only for use in boilers.

The modifications made to the *Auricula's* engine were simple and straightforward. For example, the pressure at which the fuel is injected into the cylinders is higher than in the standard engine in which a normal grade of Diesel oil is employed; and, at the outset, standard fuel lines and connections were used, although these have been modified in the light of service experience. A most important change concerns the arrangements for securing an enhanced standard of purification of the fuel oil, by means of two-stage centrifuging. The first stage is dealt with by a standard Alfa-Laval purifier, whence the fluid passes to a second machine, of broadly similar type, but which incorporates certain changes in the plate design of the bowl; this latter machine is known as clarifier. The purifier is large in relation to the normal-service through-put, the easier rating of the centrifuge being a not unimportant factor in the attainment of the especially good results necessary for trouble-free running.

The success achieved in the *Auricula*—independent examination has shown that her machinery is functioning very well on the heavier fuel—is of considerable importance, for it holds promise of very considerable savings to the owners when, as is contemplated, a substantial proportion of their fleet has

been converted to operate on Ordoil. The all-purpose daily fuel-oil consumption for the *Auricula* has been slightly increased—from approximately 12 tons to a little over 12½ tons—including the small amount of Diesel oil required for starting and maneuvering operations. Contrary to the indications of earlier experience in the use of heavier fuel, it is not anticipated that liner and ring wear will be greater than that associated with normal Diesel fuel. The experimental work is being continued with a view to exploring the possibility of employing even heavier fuel, and the hope is entertained that reliable maneuvering without the use of Diesel oil may ultimately be realized.

In regard to Diesel engines of the smaller categories, good progress has been made by the British Internal-combustion Engine Research Association, who report that the research program is getting into its strids at their laboratory at Slough, where excellent facilities and equipment are available to the increased staff.

In addition to experimental work on test engines, undertaken with the object of establishing methods of improving performance and durability, investigations are in progress in connection with bearing performance, noise, bending fatigue of crankshafts and torsional vibration. Use is being made in the laboratory of the latest developments in electronic techniques, and in many instances novel apparatus has been devised.

Representatives of the Association have visited Germany to study recent developments in engine design and research, and members of the Association have had the opportunity of examining, at the laboratory, examples of foreign engines, some of which have been tested in or for the laboratory.

A number of special panels have been appointed by the Research Committee to survey developments in gas turbines, pressure-charging, and torsional vibrations, and to advise the Committee as to appropriate courses of action.

Diesel-Electric Drive.

The ingenious Bowes drive, to which we have referred in previous surveys, has attracted considerable attention among marine engineers, and, if the claims made for it should be substantiated by service results, it should represent an important contribution to marine engineering progress. Not only does this electrical device provide for reversal of the propeller without the intermediary of engine-reversing gear or mechanical-reversing gearbox, but it also constitutes an efficient speed-reducing device, and, moreover, serves as a clutch between engine and propeller. In addition, electric power for auxiliary purposes may be taken from the Bowes unit, so that the number of Diesel-generating sets in the engine-room may be reduced. Again, should the drive give trouble, it is comparatively simple to couple the driving and driven units, which then constitute a solid drive. This last point is of practical significance only with the non-reversing type of Bowes unit, *i.e.*, where the engine is of the straightforward direct-reversing type, such as that in the *Coastal Liberator*—the only vessel which has so far been fitted with the Bowes drive.

This American device offers interesting scope for the employment of a single engine of comparatively high speed, without sacrifice of the advantages of a slow-running propeller; in the *Coastal Liberator*, the Hamilton-M.A.N. six-cylinder engine is rated to develop 2160 B.H.P. at 240 R.P.M., while the propeller speed is 120 R.P.M. It is claimed that the combined weight of the compact two-stroke cycle trunk-piston main engine and Bowes-drive unit is less than that of the corresponding directly-coupled engine of approximately the same rated output and designed for a service speed of 120 R.P.M. The efficiency of the Bowes drive, as assessed from the trial data of the motorship referred to, is 97 per cent. excluding excitation, or 94.7 per cent with excitation. The difference appears to be somewhat large, but is apparently explained by the fact that, in this instance, over-excitation was applied continuously to provide the necessary stability of operation. Presumably, improved results would be obtained in a future installation, and it is hoped that, when other units are built, the important reversing characteristic of the Bowes device, and its ability to provide auxiliary current from the main engine, will be

exploited. (The *Coastal Liberator* is provided with two Diesel-generator sets, each of 250 B.H.P.)

The unit should prove attractive in oil-tank ships equipped with rotary cargo-oil pumps which require large electric motors; for the employment of the main engine and Bowes unit as a generating set for port duty would seem to offer a useful economy in first cost. Stand-by power would, naturally, have to be provided with such an arrangement, and, it may be added, an exceptionally reliable main engine would be necessary, especially with a single-screw layout.

An interesting Diesel-electric propelling installation of the year is that of the single-screw passenger motorship *Saga* (390 feet 0 inch B.P., by 55 feet 0 inch moulded, by 32 feet 11 inches moulded to shelter deck, and 6545 tons gross), built for Rederiaktiebolaget Svenska Lloyd, Gothenburg, by the famous Götaverken company, for the owners' London-Gothenburg service. The installation consists of four Götaverken Diesel engines, developing together 6700 I.H.P. at 270 R.P.M. Each engine has eight cylinders, the cylinder diameter being 500 millimeters and the stroke 700 millimeters.

The power is transmitted to the propeller shaft by means of Asea electric slip-couplings and reduction gearing, and the *Saga* is the first large Swedish passenger ship in which this system has been adopted. Among the advantages claimed for it are the economy of headroom in the machinery space—resulting from the relatively small height required to accommodate the four quick-running engines—and the possibility of effecting adjustments to one of the units, while the remainder continue to provide sufficient power to propel the ship at a speed only a little less than the normal service speed of 18½ knots.

Miscellaneous.

For many years, there has been little major change in the design and manufacture of marine refrigerating plant in this country. A number of firms have catered for this highly specialized equipment, and there have been few important developments in design or practice, but the wider employment of the refrigerant known as Freon is one of the changes which should be mentioned.

It is interesting to remark that steam-jet refrigeration, which has been developed both here and in the United States, has begun to find an increasing sphere of application in this country. While steam-jet refrigerating plant is not by any means new or novel in this country—the *Empress of Britain* and the *Queen Mary* were both equipped with such plant—its wider use for air-conditioning purposes in warships and recent passenger liners has to be recorded. At the present time, at least two important mercantile vessels now being built are to have equipment of this type; and as the refrigerating plant will be installed between the boilers and the ship's sides, very little, if any, useful space will be sacrificed. Again, somewhat similar, if smaller, plant is being provided in a new oil-tank ship, where it is to be installed on a stringer at the after end of the engine-room.

If expediency dictates, the pumps associated with the equipment may be located elsewhere (*e.g.*, in the engine-room, adjacent to other pumps concerned with the main machinery), while the so-called flash chambers and the condenser may be located in any convenient position—on another deck or elsewhere in the ship. The main essentials of this equipment are the flash or vacuum chambers, a simplified form of steam-jet thermo-compressor (having no moving parts) which drives the vapor from the flash chamber, a condenser with air ejectors, pumps for circulating chilled water to the heat-receiving apparatus, and condensate pumps for returning the condensed steam to the feed system. Details have been given in an informative paper recently presented by Mr. W. Sampson before the Institute of Marine Engineers. The design is one which is undoubtedly attracting considerable attention, for it is simple, quiet in operation, has no mechanical parts, needs no lubrication and can be automatically controlled. It seems particularly well adapted to the requirements of air-conditioning schemes on shipboard, and, being of moderate weight, it is likely to receive increasing consideration for new passenger tonnage.

the specific fuel consumption has increased appreciably. Therefore a single, direct-drive diesel will operate unfavorably for an appreciable proportion of the time. With multiple power plants, either geared or electric, a portion of the plant may be shut down during low power periods allowing the remainder to deliver the requirements at a relatively high load factor.

Also with electrical direct-current drive the maximum power may be supplied for several different conditions of operation.

Direct-current electric drive, like the geared drive, has the advantages that the equipment is smaller and lighter than the direct drive; can be serviced and installed more conveniently and economically; and can offer greater reliability, the vessel being able to continue operation even when one engine is forced out of commission.

The applications where these advantages are important are not so extensive and the advantages themselves are counterbalanced by serious disadvantages.

Direct-current diesel-electric equipment costs close to 50 per cent above the cost of direct or geared drives.

There is a loss of approximately 15 per cent in the electrical equipment, a major factor in comparing fuel costs. Electrical equipment is large in size and requires special techniques for operation, maintenance, and repair. Controls are extensive and complicated.

Direct-current generating units operate at moderate speeds (500-850 revolutions per minute), so that diesel-electric plants require more room than a geared diesel plant.

There is increased noise, maximum firing pressures and wear.

Direct-current diesel-electric propulsion equipment cannot be used for shipboard auxiliary purposes, because it operates on a variable voltage.

New Developments.

The aforementioned types constitute the present basic diesel marine drive. Direct-drive units are far and away the most popular. Engine manufacturers have learned to build praiseworthy reliability into their equipment, and, as a result, there are actually many makes of diesels, of various horsepower ranges, which can offer continuous, reliable, close-to-full-load operation for many days or weeks at a time without respite. With this dependability available, and with the excellent fuel economy of direct-drive units, their continued popularity is understandable. However, new developments are bound to exert pressure from the standpoint of less weight, less space, greater overall vessel reliability, and, possibly, less initial cost.

Alternating Current.

One promising new development is the use of alternating current rather than direct current. It is lighter, cheaper, can be run faster and is much more rugged and cheaper to maintain than direct-current equipment. Its efficiency, however, is not much better than direct-current and in maneuverability characteristics it is complicated, slow, and in general, is not even as good as the direct-reversible diesel. Also, it is inflexible from the standpoint of supplying maximum power for various operating conditions, and it cannot vary its torque conversion properties at all. This means that it acts identically as a fixed ratio reduction gear and, where hull resistance changes, the machinery cannot change to suit.

Alternating-current equipment, however, can be useful in multiple generating sets for large powers, in cases where maneuverability and variable torque conversion is not important, and where the overall vessel requirements preclude mechanical coupling of the engines to the propeller. It also can offer large amounts of power in port, without the necessity of special or over-sized auxiliary units for that purpose alone. However, since the main propulsion equipment is operating on variable frequency its electrical power is not suitable for auxiliary purposes at sea, except for limited periods and particular applications; but one or two of the main generating units could be operated on constant frequency as auxiliary units, thereby effecting a uniformity of major power units on the vessel.

The Bowes Drive.

A highly interesting variant of the alternating-current, variable-frequency drive, now attracting attention, is the Bowes Drive, an ingenious electrical device which effectively combines an alternator and a synchronous motor into one piece of equipment. There are three major elements composing the equipment: (1) an engine element with field winding, attached to the engine crankshaft and rotating with it, (2) a doughnut-shaped secondary element outside of the engine element, with windings on both the inner and outer circumferences and mounted on either the propeller or the pinion shaft, and (3) a stationary element, concentric with the other rotating pieces and outside them, with field windings on its inner circumference.

The advantage of this drive is that it transmits a great deal of its torque by reaction exactly as does the electrical coupling. The balance is transmitted electrically just as any alternator-synchronous motor combination. Because some of the power (depending on the gear ratio) is transmitted by reaction, the efficiency is high and actually can be higher than 95 per cent. Also, there is available a design for electrical reversing.

The advantages claimed are: (1) a disconnectable coupling, (2) speed reduction from engine to propeller shaft, (3) elimination of torsional vibrations, (4) electrical reversing, (5) electrical power available at the dock by braking the propeller shaft, and (6) electrical power at sea under certain conditions.

It has, of course, the operating disadvantages of alternating current—no variable torque conversion, and slow electrical maneuvering operation. However, as a single engine, moderate ratio, electrical reduction gear, it is far better than anything else available. For this function, and perhaps with the use of a rectifying unit to obtain a useful auxiliary voltage, it will have applications and should be watched.

The Controllable-Pitch Propeller.

A further new development which will find popularity for some applications, particularly as a competitor for the variable torque conversion features of the direct current electric drive, is the controllable pitch propeller. A large number of patrol vessels, built during this past war, were equipped with controllable pitch propellers, driven by radial diesel engines, mounted with crankshafts vertical, through a right-angle gear drive.

Advantages are:

1. Variable torque conversion without loss of efficiency.
2. Reversibility, smoothly and speedily, eliminating the need for the engine reversing mechanism.
3. Smooth speed regulation from full speed to zero.
4. Better adjustment of the engine load factor for all operating conditions.

Hydraulic Drive.

One of the most promising power transmission mediums of the future is the hydraulic equipment of the rotary, pump-and-motor combination type. This hydraulic equipment can compete closely in efficiency, weight and size with electrical equipment; has a good, if not better, torque conversion and maneuvering properties; and has the additional attractiveness of being completely mechanical. In cost, too, it should be competitive with marine electrical equipment, particularly since its controls are very simple.

War Developments in Geared Diesels.

Even before the war, the problem of gear pounding was brought under control successfully by importations from Europe—electric and hydraulic couplings. A large number of ships have been built in the United States with this equipment during the war. The coupling, either electric or hydraulic, is installed between the engine and the gear and isolates engine speed pulsations from the reduction gear, thus allowing smooth transmission of power; serves as a disconnecting coupling, allowing instantaneous disengagement should one of the engines become disabled; and in the case of towboats allows one of the

engines to run "Ahead" and the other "Astern," which with coupling manipulation, gives excellent maneuvering characteristics.

Couplings add to cost and decrease efficiency (2 to 3 per cent) but they eliminate one of the major problems of geared equipment.

Experience shows that the gears themselves are reliable. It might reasonably be concluded that the geared diesel drive will enjoy an increase in popularity.

Applications to Various Types of Ships.

Towboats. The harbor tug requires low propeller speed for maximum thrust at low vessel speeds. Full torque conversion for all types of tows and rapid maneuverability for speeding up the docking operation are definitely desirable. These requirements may best be filled by the direct-current electric drive, although the problems of cost and complication are difficult hurdles. Installation of electrical drives on seagoing tugs, where rapid maneuverability is not often required, is not equally justified.

Ferries. In general, the direct drive, direct reversible diesel has been most popular for ferryboat installations. It is to be expected that this type engine and the geared diesel will continue in popularity. However, for runs where ability to maneuver may be an appreciable factor in overall operating time, direct current diesel electric drive may be useful.

Cargo Vessels. Low fuel consumption and high reliability are the major requirements of the cargo vessel. Low-speed, direct-drive, or multiple, medium-speed, geared diesels answer these requirements.

The major auxiliary load for cargo vessels occurs at the dock during winch operation. Therefore, diesel-electric propulsion machinery, which can handle this auxiliary load at the dock and thereby fill a dual purpose, has an attractive first-glance argument. The penalty, however, of electric propulsion losses at sea, as well as first cost, is a distinct disadvantage.

Furthermore, with tendency for carrying refrigerated cargo and air-conditioning equipment, which can constitute an appreciable sea-load, there is additional reason for separate auxiliary power.

Tankers. The direct drive or geared diesel seems, for the same reasons as for cargo vessels, most suitable for tankers. However, like cargo vessels, tankers need appreciable power at the dock for loading and unloading. Nevertheless, the penalty of electrical propulsion losses and first cost is high.

Dredges, in general, have an appreciable power load besides the main pumps. Cutting equipment, jet pumps and swinging machinery all require appreciable amounts of flexible power. There is good reason, therefore, for careful study of a diesel-electric installation. Indeed, the flexibility required is so great that many installations have used several independent generators driven by a single engine.

When the dredge is self-propelled, there is additional reason for a diesel-electric installation. The power required by the main pumps and the power required for propulsion are both appreciable and, since peak pumping and propulsion loads occur alternately, and practically never simultaneously, one set of prime movers is sufficient for both functions, thereby saving appreciable space and weight.

Yachts. Reliable, light, and compact machinery is required for yachting service. Medium-speed direct-drive or probably geared diesels are particularly applicable for this service.

Ice-Breakers, Survey Boats, Coast Guard Cutters and Salvage Vessels. Electric drive's torque conversion, maneuvering and operating capabilities have particular usefulness in such vessels. The versatility of the direct-current power plant in performing the various assigned duties is an expensive but generally useful feature.

Fishing Trawlers and Seiners. Reliability and simplicity are the dominating requirements for all kinds of fishing vessels.

Since auxiliary loads are periodic and moderate, the use of electric drive appears to have the important advantages of being able to accomplish a dual function. However, the necessity of simplicity and low first cost explains the

direct drive's continuing popularity. It is to be expected, however, that geared units will enter the field.

The torque conversion quality of electrical equipment is advantageous when towing nets, thus making electrical equipment desirable for more reason than its ability to supply power to the winches. A careful study may show it sufficiently valuable to warrant an introductory installation.

Technical progress has made available engines which, while operating at much higher speeds, have retained the dominant feature of reliability. This technical progress cannot be ignored. The higher speeds require either the use of indirect drives, or the acceptance of a lower propeller efficiency, at least until further developments are made by the propeller designers.

Although the indirect drive will find more and more consideration in the future, it is hoped that the low fuel consumption and extreme simplicity of the direct drive will be retained to as great a degree as possible.

A logical corollary to low fuel consumption is the use of low-cost fuels. Too much emphasis can hardly be placed on the importance of this single item on the overall cost of power production in many applications. In this connection, choice of engine speeds for indirect drive should take into account the use of low-cost fuels.

Finally, it is suggested that motorship operators give consideration to the establishment of a cost analysis consumer organization similar to the Diesel Engine Users' Association which has operated for many years to the great benefit of stationary plant operators and engine builders. The returns should be well worth the relatively small expenditure required.

ATOMIC ENERGY AND ITS APPLICATIONS.

Since the bursting of the atomic bombs over Nagasaki and Hiroshima much has been written and published on atomic energy. This paper, written by a famous British physicist, Sir James Chadwick, and reprinted from the December 1946 issue of "The Institute of Fuel" is one of the most complete and understandable of the scores of papers which have appeared. It gives a comparatively simple description of an atomic reaction and then tells how it may be applied to the production of power. Finally, it gives a realistic viewpoint of the limitations on atomic power and some idea of its future.

The great technological developments and achievements of the past century or so, which are the dominating features of present-day civilization, constitute an increasing control over the processes of Nature. These developments and this control have grown from an ever-widening knowledge and understanding of natural phenomena. At no time has the rate of advance of scientific knowledge and the rate with which this knowledge has been put into practice and exploited for technical developments been so rapid as in recent years. This is especially the case in the physical sciences in which the most remarkable advances have taken place during the past 50 years.

These discoveries have given us the first real insight into the internal structure of the atom. We have learned that each atom consists of a cluster or cloud of negatively electrified corpuscles, the electrons, held together by the attraction from a positively charged nucleus, which, although it contains practically the whole mass of the atom, is extremely small in size compared with the dimensions of the electron cloud.

The many problems connected with the configuration of the electron cluster have been studied most successfully, and the results have led to a complete clarification of the relationship between the 90 or so chemical elements as regards their ordinary physical and chemical properties.

All the ordinary properties of matter, such as strength and hardness, elasticity, electrical conductivity, chemical affinity, etc., on which all the processes involved in industrial and scientific developments depend, are determined by the configuration of the electron cluster and are practically independent of the structure of the atomic nucleus.

This is because the ordinary physical and chemical agencies produce no change whatever in the properties of the nucleus but affect only the general atomic structure by distorting or disrupting the electron configuration.

The stability of the atomic nucleus under all ordinary conditions is the basis for the doctrine of the indestructibility of matter and the immutability of the elements, which for so long was a cardinal doctrine of physics and chemistry.

Thus the discovery of radioactivity in 1896 opened a new epoch of science, for, as Rutherford and Soddy showed so conclusively, the phenomena could only be explained by the assumption that the atoms of uranium, radium and other radioactive elements were unstable and were continuously breaking up and changing, at rates characteristic for each, into other elements.

It was, in fact, as a result of experiments in which the radiations from radioactive elements were used as a tool for the exploration of the structure of atoms that Rutherford was later led to the hypothesis of the nuclear structure of the atom; and it was the combination, proposed by Bohr, of this idea with the quantum theory of radiation which led to the great progress in our knowledge of atomic structure to which I have alluded.

One of the most striking facts in the radioactive phenomena is the amount of energy released in the form of radiation, an amount which, atom for atom, is comparably greater than that connected with any chemical reaction. It had to be recognized, however, that this energy release had no practical value, for the reason that the rate of release is slow and it cannot be influenced in any way. For example, energy is emitted in the decay of 1 g. of uranium (with its products) at the rate of rather less than 1 calorie per year, so that it would take more than 100 years to raise 1 c.c. of water to boiling point. On the other hand, the lifetime of uranium is so long that the total amount liberated during the transformation of 1 g. of uranium to lead would be 5000 million calories. We can compare this with the 8000 calories liberated in the complete burning of 1 g. of coal.

It became clear therefore that there is a reservoir of energy in the interior of the atoms of matter which is enormously greater than that available from any known chemical process. But as all attempts to influence the transformation of a radioactive element were of no avail, the prospect of any practical application seemed exceedingly remote.

The first step along the road to the practical use of atomic energy was made by Rutherford in 1918 when he found that the high-speed α particles from radium-C could in rare instances collide with a nitrogen atom in such a way that the nitrogen nucleus broke up, forming two other nuclei, hydrogen and oxygen.

This discovery was extended by experiments in which it was found that many other light elements could be transmuted in a similar way, and, later, by the work of Cockcroft and Walton, who showed that fast protons, or hydrogen nuclei accelerated to a high velocity by means of an electric field, produced transmutations in lithium and in many other elements.

Many of these transmutations were accompanied by a release of energy which, per nuclear reaction or per particle involved, was millions of times greater than the energy released in the most violent chemical reaction. But the number of nuclear reactions was so small that the total amount of energy released was minute compared with the total input of energy used in producing the bombarding particles; thus while the scientific results were of great importance, their practical value was negligible.

Any scheme for the release of atomic energy which involves bombardment by charged particles seems bound to be inefficient. One reason is that the nucleus is so minute that a direct collision between the bombarding particle and the nucleus, such as is required to break up the latter, is a very improbable event. A second reason is that, since both the nucleus and the bombarding particle are positively charged, the force of repulsion between them greatly reduces the chance of a collision. Only particles of very high energy can overcome this force of repulsion and nearly all the particles will lose their

energy in collisions with the electrons which surround the atomic nuclei before they reach the nucleus itself.

The next important step was the discovery of the neutron, an uncharged particle of slightly greater mass than the proton. The neutron and the proton are, we believe, the two units from which all atomic nuclei are built up, and they are related to each other in some way not yet fully understood.

Because of its lack of electric charge, the neutron is an ideal projectile for carrying out nuclear transformations, and it was, in fact, quickly found that a great number of nuclear reactions could be produced by neutron bombardment. Especially with slow neutrons, the reactions were strikingly efficient, and in some cases practically every neutron produced a nuclear transmutation. The over-all picture of the economy of the process was still very poor, however, because the neutrons themselves could only be supplied as the result of one or other of the very inefficient processes of transformation in which a charged particle was used to bombard an atomic nucleus. The practical value of these reactions was still completely negligible, and there appeared yet no way of releasing for useful purposes the enormous amount of energy stored in the nuclei of atoms.

The scientific results were, of course, very interesting, and they gave an immediate clue to the origin of the energy sources present in the interior of the stars, till then quite unknown, and in particular it became possible to explain how our sun has been able to continue, for billions of years, to emit the radiation upon which all organic life on the earth depends and from which all our common energy sources, such as coal, oil, etc., derive their origin.

The temperature in the interior of the sun is about 20 million degrees. At such a temperature the atoms have so high a velocity of thermal agitation that the nuclei come into collision and reactions can take place on a large scale. The release of energy maintains the high temperature and the degree of thermal agitation, so that the reactions continue and maintain an uninterrupted flow of energy from the interior. It is generally supposed that the following cycle of nuclear changes takes place:—

$$
\begin{aligned}
&(1)\ C^{12} + H^1 \rightarrow N^{13}\\
&(2)\ N^{13} \rightarrow C^{13} + \text{positive electron}\\
&(3)\ C^{13} + H^1 \rightarrow N^{14}\\
&(4)\ N^{14} + H^1 \rightarrow O^{15}\\
&(5)\ O^{15} \rightarrow N^{15} + \text{positive electron}\\
&(6)\ N^{15} + H^1 \rightarrow C^{12} + He^4
\end{aligned}
$$

The reaction starts between carbon and hydrogen and continues through a cycle in which the carbon is restored. The net result of this cycle is the transformation of hydrogen into helium, with the release of a large amount of energy:

$$4H^1 \rightarrow He^4 + 2e^+ + Q$$

Such thermo-nuclear reactions, nuclear reactions in which the velocity of the particles is due to thermal agitation, can only be produced at exceedingly high temperatures, so high that it is not easy to imagine how the conditions could be realized in a laboratory, for even the most easily stimulated nuclear reaction we know, that between two nuclei of deuterium or heavy hydrogen, would not proceed at a noticeable rate below a temperature of about 200000 degrees C. or so.

Thus, as Lord Rutherford said in one of his last public statements: "The outlook for gaining useful energy from the atoms by artificial processes of transformation does not look promising."

The turning point came with the discovery by Hahn and Strassmann, in January, 1939, that the transformation of uranium produced by neutron bombardment was a very different process from what had hitherto been supposed, and that the uranium nucleus, in some cases at least, split into two fragments of roughly equal mass.

Frisch and Meitner explained this process of nuclear fission, as it is called, in terms of the general theory of nuclear reactions developed by Bohr. They

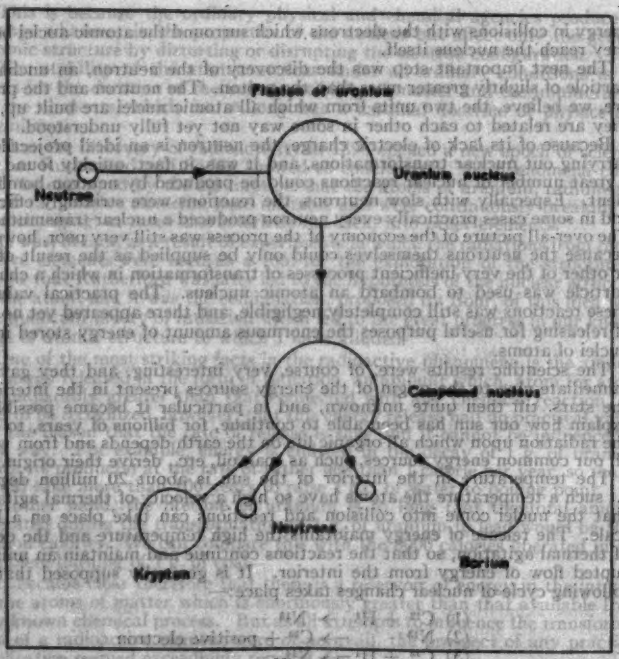


FIG. 1.

also pointed out that the fragments would fly apart with immense energy, and this was soon confirmed experimentally.

Shortly afterwards, both in France and in the United States, it was shown that in the process of fission of uranium some neutrons are also emitted, certainly more than one and possibly as many as three in each process.

The fission process can be briefly described as follows. A neutron is captured by a nucleus of uranium 235, forming a nucleus of uranium 236, in a highly excited state. This immediately divides into two fragments of roughly equal mass, and at the same time from one to three neutrons are emitted (and also some γ-radiation). The fragments fly apart with considerable speed and, in their passage through matter, their energy of motion is finally transformed into heat. These fragments are, in general, unstable and may pass through a series of transformations, emitting β-particles and γ-radiations, before they reach a stable configuration. The diagram of Figure 1 represents one mode of fission, in which the fragments as first formed in the fission process, are unstable nuclei of barium and krypton.

It was immediately recognized that this discovery was of the greatest significance and that it opened up the possibility of a practical utilization of the enormous store of atomic energy. Not only did the fission of uranium release a large amount of energy, but the emission of more than one new neutron each time that a nucleus suffered fission suggested the possibility that the reaction could be propagated from atom to atom, developing a whole chain of reactions from one single event. Such a chain process developing

in a mass of uranium might take place at an ever-increasing rate and might involve so many atoms that there would be an appreciable, and possibly an overwhelming, liberation of energy. In this way it seemed that a new type of combustion of matter might be possible which would give an energy yield a million times greater than that obtained by the combustion of the same weight of coal or oil.

This prospect naturally attracted widespread interest, and many investigations were made on the mechanism of the fission process. These investigations revealed a striking difference in the behavior of the two main isotopes of uranium. The common isotope 238, which forms more than 99 per cent of natural uranium, undergoes fission only when the bombarding neutrons have a high energy; the rarer isotope 235, occurring to the extent only of 0.7 per cent in natural uranium, undergoes fission with neutrons of any velocity and is especially liable to fission with very slow neutrons.

The great preponderance of 238 and its relative inactivity to neutrons makes natural uranium unable by itself to sustain a chain reaction. On the other hand, the isotope 235 possesses just the properties which are required, but it has to be separated in a relatively pure form from the ordinary uranium.

This is a very difficult operation, since the two isotopes are almost identical in every property but that of mass, and even in mass they differ by little more than 1 per cent. Nevertheless the separation has been accomplished in two different ways, by an electromagnetic process and by a gaseous diffusion process, and both processes have provided adequate quantities of 235.

Plutonium.

In the course of the investigations of the nuclear properties of uranium another fission material was discovered. This is a new element—plutonium—which does not occur in Nature, but has to be made by a transmutation process.

When the abundant isotope U238 is bombarded by neutrons, and especially when the neutrons have speeds within certain special ranges known as "resonance bands," a neutron may be captured by the 238 nucleus. The nucleus of U239 so formed is radioactive, breaking up after an average time of about 34 minutes with the emission of a β-particle. The new nucleus, neptunium, of atomic number 93, is also unstable and changes after an average time of three days to plutonium, an element of mass 239 and atomic number 94.

$$U^{238} + n \rightarrow \ldots\ U^{239}$$
$$U^{239} \rightarrow \ldots\ Np^{239} + \beta\text{-particle}$$
$$Np^{239} \rightarrow \ldots\ Pu^{239} + \beta\text{-particle}$$

Plutonium is also unstable, but its rate of disintegration is so slow that, like radium, it can be accumulated. Sufficient quantities were made to enable its nuclear properties to be examined, and it was found that plutonium would undergo fission with neutrons of all speeds and that it was as suitable as uranium 235 for use in a chain reaction.

The manufacture of plutonium in quantity is clearly a formidable operation, for it has to be made atom by atom. It is necessary to expose amounts of uranium of the order of some tons to an enormous source of neutrons—such a source as can only be supplied by a chain reaction itself.

Before describing how this has been done, I must return for a moment to some simple considerations of the chain reaction and the behavior of fissile materials.

Maintenance of Chain Reaction.

A chain reaction will not necessarily develop in any piece of fissile material. Certain conditions must be satisfied. In the first place, the amount of fissile material or the reacting system as a whole must be of such size that there is not too great a chance that the neutrons produced in the fission process can escape and so be unable to carry on the chain. Secondly, the system must not contain more than a limited amount of material which absorbs neutrons, for in this way again the neutrons will be prevented from continuing the chain reaction.

If these conditions are satisfied, the chain reaction will develop and "run away," unless some special device is introduced to control it. Thus we have two general types of chain reaction—the uncontrolled reaction and the controlled reaction.

Uncontrolled Reaction: the Atomic Bomb.

If we wish to use atomic energy as an explosive the reaction must be uncontrolled, for the more rapidly it can proceed, the greater will be the amount of energy set free and the explosive effect.

The question of size is critical for an atomic explosion, for a chain reaction cannot develop if the mass of fissile material is too small. This is because the reaction depends on the conservation of the neutrons produced in the fissions. If the piece of material is too small or of an unsuitable shape, too many neutrons will escape before they hit a nucleus and propagate the reaction. The proportion of neutrons which escape can be reduced by increasing the size of the piece, since the production of neutrons is a volume effect and will therefore increase more rapidly with size than the loss of neutrons by escape, which is a surface effect. Thus a certain minimum amount of material is required, called the critical size or amount, before the reaction can develop so fully that an explosion occurs. If the piece of fissile material is less than the critical size it will be quite stable, but as soon as it exceeds this a chain reaction will develop and multiply itself with enormous rapidity. Thus all that is necessary to detonate a bomb of uranium 235 is to bring together two pieces each less than the critical size but which when in contact exceed it.

Suppose we have succeeded in doing this by some means, and that at the same moment we shoot a neutron into the material. This will cause fission of one uranium nucleus and produce, let us say, two fission neutrons which in turn produce four, and so on in successive generations. Since the fission neutrons have speeds of the order of 10^9 cm. per sec., and since they do not have to travel many centimeters before they produce new fissions, the time between successive generations, in which the number of neutrons is doubled, is of the order of 10^{-9} seconds. In a millionth of a second, therefore, the number of neutrons will have increased enormously and a considerable fraction of the mass of 235 will have undergone fission. If only 1 kg. is used up in this way, the amount of energy released will be as much as from 17,000 tons of T.N.T. This amount of energy is so great that the mass will attain a temperature of many million degrees and a pressure of many million atmospheres. The high temperature causes the emission of an enormous amount of heat and light, and the sudden expansion of the hot gases produces the shock wave of the explosion.

As the material expands, the neutrons can escape more easily and the reaction stops. By this time the hot glowing gases may have expanded to a diameter of about a third of a mile.

In addition to the blast wave and the intense heat and light from the hot gases, the atomic bomb emits an enormous radiation of gamma rays and neutrons at the moment of explosion. Further, the products formed by the fission process are intensely radioactive and the total amount formed in the explosion may correspond in activity to many tons of radium.

While the principles governing the processes in the atomic bomb are very simple, there are some interesting problems connected with the assembly of the parts and with the detailed process of the explosion. These matters concern mainly the military aspects of atomic energy and have little immediate bearing on its application to industrial uses. I shall therefore not discuss them further on this occasion.

Control of the Chain Reaction.

In order to use atomic energy for industrial purposes it is obviously necessary to control the chain reaction so that the energy can be released continuously and at a predetermined rate. It seems at first sight that the control of a reaction which can develop so rapidly and which can liberate such enormous

energies must be exceedingly difficult. This is, fortunately, not the case, and in practice the control is remarkably simple, effective and accurate.

Control depends on the regulation of the neutron flux so that at a predetermined level the flux remains constant, only exactly as many neutrons causing fission in one generation as in the previous generation. The extra neutrons which are produced in the fissions are removed and made unavailable for the reaction. The reaction will then proceed at a constant rate. This balance can be achieved either—(1) by allowing the excess neutrons to escape from the system or (2) by capturing them in some absorbing medium.

It will be convenient at this point to define a quantity called the multiplication or reproduction factor. Let us suppose that in a system containing fissile material there is a certain number, P, of free neutrons present at a given time. Some of these neutrons will initiate fissions and thus directly produce new neutrons, Q in number. The ratio Q/P is called the multiplication factor and denoted by k.

If k is less than 1, no chain reaction can develop. Any stray neutrons may produce a fission, but the chain will die away quickly and the system will be perfectly safe. This corresponds to a system which contains less than the critical amount of fissile material.

If k is greater than 1, as in the example quoted above for the atomic bomb, the number of neutrons will increase rapidly from generation to generation and an explosion will occur.

When k is exactly equal to 1, the reaction will proceed at a constant rate and the flux of neutrons will remain constant. This is the condition which has to be achieved for successful application of the chain reaction to general purposes.

The diagrams of Figure 2 show in a rough way the conditions in a divergent chain reaction and in a balanced reaction. In the latter case, one of the two neutrons assumed to be released by fission, indicated by a short stroke, is absorbed and takes no part in the propagation of the reaction.

The principle of the control of a chain reactor can be illustrated by a simple example. Let us suppose that we have two masses, A and B, of fissile material, each less than the critical amount but together considerably greater than it, and let us consider what happens as A and B are brought closer together.

When A and B are far apart, the leakage of neutrons will be great and the multiplication factor k will be less than 1. Suppose that at some stage in the approach k becomes equal to 0.99 and that we have in the material a source of neutrons which emits 1 neutron per second. This one neutron will produce k neutrons in the first generation, these k will produce k^2, and so on, so that the total number of neutrons being produced per second will be:

$$1 + k + k^2 + k^3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots = \frac{1}{1-k}$$

if k is less than 1.

Thus when $k = 0.99$ there will be 100 neutrons produced per second in the material and the primary source has been multiplied 100 times. As the two parts are brought closer and closer together the leakage of neutrons diminishes, k becomes correspondingly nearer and nearer to 1, and the neutron intensity can be brought to any desired value.

It is evident, however, that an exceedingly fine adjustment of k will be required to reach a high intensity, so fine as to be impossible as a practical operation.

Let us now suppose that the two parts are close enough to make k slightly greater than 1. A divergent chain reaction will now develop and the neutron intensity will rise rapidly, doubling itself in each successive interval of time T given by the formula

$$T = 0.7\frac{\tau}{k-1}$$

where τ is the average lifetime of one generation of neutrons.

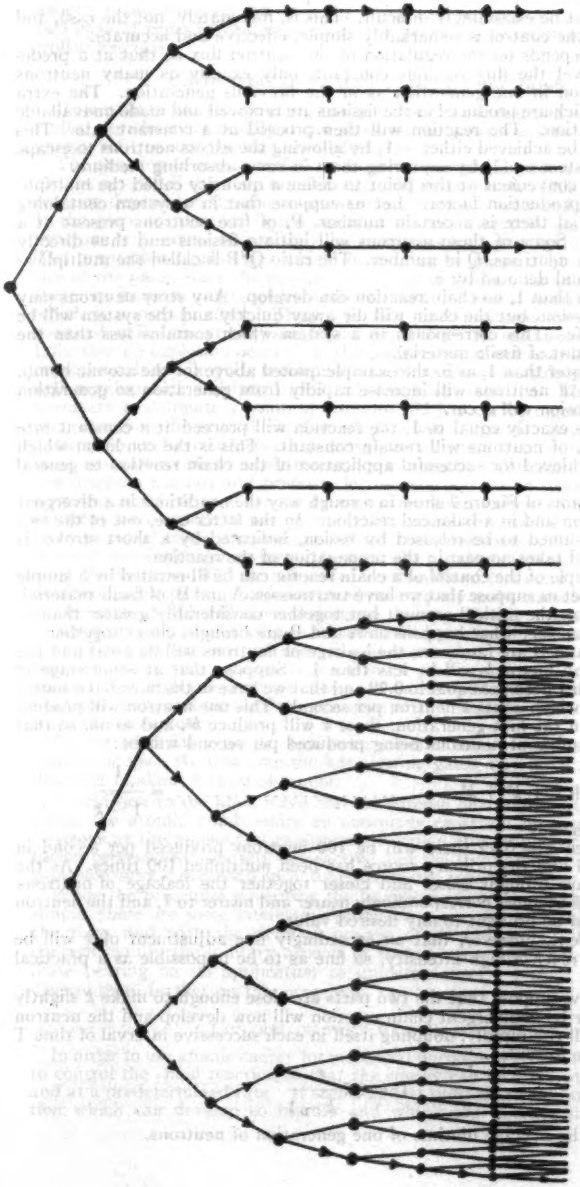


FIG. 2.

Thus by making k slightly greater than 1 we could raise the level of neutron intensity very rapidly and, having reached the level it is desired to have in our reactor, we could now reduce k to 1 so that the desired level would be maintained.

While this adjustment is simple in principle, the possibility of carrying it out depends very much on the value of τ. Now the fission neutrons are emitted with velocities of the order of 10^9 cm. per second, so that if they were all emitted instantaneously upon fission the value of τ would be of the order of 10^{-8} seconds. But in order to allow time for the adjustment of the mechanisms which control the positions of A and B we need a doubling time T of the order of a second; and this would entail an adjustment of the value of k to less than one hundred-millionth part of its value. Even if this could be achieved, there would always be the danger of a slight temperature change or mechanical disturbance which might cause the neutron intensity to rise at an uncontrollable rate and result in a violent explosion.

If the picture I have given were quite accurate, the control of the chain reaction would evidently be a formidable operation. Fortunately, however, not quite all the neutrons are emitted instantaneously upon fission. Some of the fission products transform after a time with the emission of a β-particle into nuclei which are now unstable and emit neutrons.

We have therefore in addition to the prompt neutrons released in the fission process itself some neutrons which are delayed after the fission by the time required for the transformation of the fission fragments. The effect of these delayed neutrons is to increase the average time for neutron generation and, therefore, to reduce the rate at which the chain reaction develops.

The importance of this effect can be shown by a simple calculation.

For the purpose of this calculation we may assume that the delayed neutrons form 1 per cent of the total neutron emission from fission and that the average time of delay is 10 seconds. We now arrange the assembly of fissile material so that it is only just above the critical condition, with a multiplication factor k greater than 1 but less than 1.01. This means that the prompt neutrons alone will be insufficient to maintain the chain reaction and each generation of neutrons will have to wait for the delayed neutron emission before a divergent increase in intensity can occur. The neutron intensity will double itself for each interval of time T given by

$$T = 0.7\,\frac{1 - k_p}{k - 1}\,\tau_D$$

where k_p is the multiplication factor due to the prompt neutrons alone, and τ_D is the average time between the fission and the emission of the delayed neutrons, that is, 10 seconds.

If we put $k = 1.005$, then k_p will be about 0.995, and the doubling time is about 7 seconds.

Thus, provided the assembly is only a small degree above the critical size, the effect of the delayed neutron emission is to make the reaction grow quite slowly. It will therefore be easy to control the reaction and to hold the level of the reaction and the neutron intensity at any desired level. The adjustment of the neutron leakage may be a simple type of mechanical control which moves a small part of the reactor relative to the main system or which moves reflectors which can reflect back into the system some of the neutrons which would otherwise escape. In this way the reaction can be controlled smoothly and the level of the reaction can be held very steady; in fact, in some of the so-called "slow reactors" the level can be held to better than one part in 10,000 over long periods of time.

Fast Neutron Reactor.

The systems I have so far considered are known as fast neutron reactors, because the chain reaction is carried on by the fission neutrons without moderation of their speed except that which inevitably must occur in collisions

in the system, whether in the fissile material itself or in parts of the apparatus for assembly, etc., and these neutrons have velocities of the order of 10^9 cm. per second.

Slow Neutron Reactor.

Slow neutrons, however, are much more effective in producing fission both in U235 and in plutonium than are fast neutrons. Thus, if the fission neutrons could be slowed down before reproducing themselves, the chain reaction could be maintained in a smaller amount of fissile material or even in much less pure material than is required for the fast reactor.

The neutrons can be slowed down by causing them to make collisions with light atoms such as hydrogen, deuterium, helium, carbon, etc. In each collision some of the energy of motion of the neutron is transferred to the atom with which it has collided and the neutron is slowed down in a series of steps. The slowing-down process, or moderation as it is called, cannot continue indefinitely, since the atoms of the material in which the collisions take place, the moderator, are themselves in motion by reason of their thermal agitation. If the process proceeds far enough a limiting stage will be reached when the energy of the neutrons is on the average equal to the energy of thermal agitation of the atoms of the modulator. Clearly, this stage will be reached more quickly the lighter the colliding atom, so that hydrogen will be the most effective moderator, with deuterium next, and so on.

A considerable amount of moderator will be required, so that in practice one would use hydrogenous substances such as water or paraffin. Owing to the much greater effectiveness of slow neutrons, the critical amount of fissile material which is required to maintain a chain reaction in a slow reactor can be reduced to a small fraction of the amount needed for a fast reactor. This is, however, not a point of much importance if it is desired to use the reactor as a generator of power, owing to the difficulty of removing a large amount of energy rapidly from a small space. It does, however, permit the building of quite small reactors for research purposes.

One advantage of the slow neutron reactor is the simplicity of control. Some substances, notably boron and cadmium, absorb slow neutrons very strongly. This fact provides a very ready method of controlling the reaction, by moving rods of these materials in or out of the reactor and so adjusting the multiplication factor by changing the loss of neutrons by absorption rather than by changing the loss by leakage as in the fast reactor. It is obvious that a simple mechanical device will suffice to carry out this control.

A very important advantage offered by the use of slow neutrons is that it is no longer necessary to use pure or nearly pure fissile material in order that the chain reaction should maintain itself. In fact, as is well known, it is possible to use natural uranium, thus avoiding the very expensive and tedious process of separating the isotopes.

In this case, owing to the fact that the 238 isotope captures neutrons without undergoing fission and that this isotope is 139 times as abundant as the fissile 235, the choice of material for slowing down the neutrons is rather limited, for very little additional loss of neutrons can be tolerated. For this reason it has not been found possible to use water as moderator, for hydrogen captures slow neutrons too readily. Heavy water makes a very suitable moderator, for the capture by deuterium is small, and it has been successfully used in the United States and later in Canada. It is, however, too expensive a substance to use for large reactors.

The best material readily available at the present time is carbon, in the form of graphite. This has the advantage of being relatively cheap and abundant, and it can be obtained in a very pure state.

Owing to the inevitable, though small, loss of neutrons by absorption in the graphite, the multiplication factor of a uranium-graphite system is not much greater than 1. The critical size of the reactor is, therefore, rather large and some tons of uranium and of graphite are required. The construction of a reactor of small power is a straightforward matter, but difficulties arise when large power dissipation is desired, of the order, say, of 100,000 Kw, owing to

the small latitude in the multiplication factor. The nature of these difficulties will be best illustrated by a brief description of the large reactors, the so-called graphite piles, erected at Hanford, although the primary purpose of these piles was the production of plutonium rather than the generation of power.

NATURAL URANIUM REACTOR—THE GRAPHITE PILE.

For reasons depending on the nuclear properties of uranium, the arrangement which gives the highest multiplication factor is one in which lumps of metallic uranium are disposed at regular intervals throughout a large block of graphite in the form of a lattice. The ideal shape would be spherical, but for practical considerations a rectangular block is used. The optimum size of the uranium lumps and of the lattice spacing can be calculated from the nuclear constants of the materials. This was the arrangement used in the first graphite pile of very low power, but it had to be modified for the plutonium production pile. There were two reasons: first the uranium has to be cooled in order to remove the heat generated by fission, and it is difficult to concentrate the coolant at small lumps, and second, it was required to remove the uranium without disturbing the assembly of the pile.

The arrangement used in the Hanford piles is, therefore, a rod lattice of cylindrical symmetry, in which short rods or slugs or uranium are loaded in cylindrical channels in the graphite moderator. This entails some reduction in the multiplication factor.

The cooling agent, water in this case, is circulated through pipes around the rods. Since graphite pipes are not practical, on engineering grounds, some other material has to be used, and the choice is limited by the condition that the material must have a small absorption for neutrons. The material chosen was aluminum.

Further, the uranium must be protected from the cooling water, for it is easily oxidized, and even if the slugs were not disintegrated by chemical action sufficient fission products would enter the cooling water to make operation dangerous. The protective jacket must have a high conductivity in order to transmit heat quickly from the uranium to the water, it must not absorb too many neutrons, and it must not corrode. Aluminum fulfils these conditions fairly well.

The introduction of this auxiliary material in the form of cooling pipes, sheathing, instruments, etc., increases the loss of neutrons by absorption, and it is, therefore, necessary to keep down the loss by leakage to a few per cent. This is not difficult, for the leakage can obviously be made as small as desired by making the reacting system sufficiently large.

The problem of dissipating some 100,000 Kw. or so is not difficult provided an ample supply of pure water is available, but it is complicated by factors peculiar to an atomic energy reactor. In its passage through the pile, the water becomes radioactive, so that if the water is to be returned to a river a retention basin must be provided to ensure a delay, during which the induced radioactivity dies down to a safe level. Further, the circulating system must be very reliable, and fast-operating controls must be provided in order to shut down the chain reaction quickly in case of failure of the water supply.

The control is essentially no more difficult than for a small slow reactor, but, of course, the large reactor is potentially much more dangerous. The operating controls, connected with instruments in the pile, which measure the neutron density and thus the power level, can automatically keep the pile operating at a predetermined level. In addition, emergency controls are provided to operate as soon as the power level shows signs of undue increase.

The radiation from a pile operating even at low power is strong enough to be dangerous to human life, and that from a high power pile reaches a fantastic intensity. The whole of the reacting unit must, therefore, be enclosed in steel and thick walls of concrete, and it must be possible to load and unload the pile through these shields. Any operation on the pile must be carried out by remote control.

Since the Hanford piles are used to manufacture plutonium, the radiation dangers persist through a further stage of the operations. Since the fission

products resulting from the combustion of 235 are highly radioactive, the uranium slugs must be removed from the pile by remote control from behind a shield and must also be shielded during their journey to the chemical plant. All the stages of the separation plant must also be handled by remote control until plutonium is sufficiently free from fission products.

The design and operation of the Hanford piles was thus beset by difficulties, many new and peculiar to an atomic energy plant, but they have operated for nearly two years without trouble at a power level of perhaps a few hundred thousand Kw.

The total weight of a pile, including the massive shielding, amounts to some thousands of tons, but it is, nevertheless, a very compact unit for the amount of power which is generated in it.

Production of Useful Power.

The energy generated in the Hanford piles is removed by the cooling water which issues at a temperature considerably below 100 degrees C., too low a temperature for efficient conversion of the heat to useful power. If such a pile is to have general industrial applications, such as the generation of steam and the generation of electric power, it must be run at a much higher temperature. To do this will necessitate considerable changes in design and in operating technique.

It would probably be possible to use liquid bismuth as coolant instead of water, and it might be an advantage to use some other material than graphite as moderator. Progress on these lines demands the solution of some awkward engineering and metallurgical problems, but there is no reason to suppose that the difficulties cannot be overcome.

If it should prove difficult or perhaps impossible to design such an atomic energy plant to run on natural uranium, on account of excessive neutron losses in moderator, coolant and auxiliary materials for cooling pipes, etc., one can turn to uranium enriched by extra U235 or by plutonium, or even to the highly concentrated fissile materials. The use of these will permit a wide degree of flexibility in the design of the plant.

The most striking characteristics of atomic energy reactors are their compactness for large power capacity and their ability to run for long periods with little or no refuelling.

The power available from an atomic energy reactor is limited essentially only by the rate at which the heat can be removed from it, so that a million-Kw. plant need be no bigger than a normal electric power sub-station.

The energy released in the combustion by fission of 1 lb. of 235 or plutonium is rather more than 11 million Kwh., equal to the amount of energy which can be obtained from about 1500 tons of coal or 250,000 gallons of fuel oil. Thus an atomic energy unit may be able to run for long periods on one charge of fuel and the cost of transport of fuel will, in any case, be small.

Moreover, the plant may, under appropriate conditions, be able to regenerate some, if not all, of its fuel. This arises from the possibility of designing the plant so that some of the neutrons released in fission are used to produce plutonium in uranium, disposed in a suitable way inside or outside the reactor, which will replace the U235 or plutonium which is burned.

This process of replacement takes place in the Hanford piles, where U235 is indirectly converted into plutonium. It may be possible under some conditions to arrange that as the 235 is burned the reaction could continue by burning the plutonium, and in this way most of the uranium 238 as well as the 235 might be utilized.

This relative freedom from supply problems, once the plant is set up, opens up the possibility of stimulating industrial development in isolated parts of the world, where coal or water power are not readily available.

For the same reason, it might prove advantageous to establish atomic energy units in close proximity to mines, more especially in those cases where the ores have to be transported long distances in their crude states.

They may also find application in large ocean-going vessels, in cases where it is desired to avoid frequent refuelling. This application is somewhat more

questionable on account of some aspects of atomic reactors, to which I shall refer in a few minutes.

We must not forget, however, that these bright prospects for the peaceful applications of atomic energy depend on the solution of difficult engineering problems, and that no reactor has yet been developed, or, I believe, even designed, which is suitable for the purposes I have mentioned.

Nor must we forget the limitations and disadvantages to which the atomic energy unit is subject, and which are inherent to it.

One of the most serious disadvantages from the view of general industrial use arises from the fact that an atomic energy reactor is a source of very intense and very dangerous radiations. A reactor operating at a power level of 1 watt produces as many γ-rays as a few grams of radium* and some neutron radiation as well. Although a considerable fraction of these radiations will be absorbed in the reactor itself, shielding is required in order to protect personnel in the vicinity. Even in the case of a very compact unit, the weight of shielding will be considerable.

For example, let us take the case of a reactor dissipating (not generating as useful energy) 100,000 Kw. This cannot be much less in size than a 1 meter cube, having regard to the difficulty of the problems of heat transfer. It is easy to show that the weight of the shielding required to reduce the radiations from this unit to a safe level would be a few hundred tons.

Even a low-power reactor will need shielding at least 50 to 100 tons in weight, and this factor alone prohibits the application of this type of power to motor cars or any small mobile units.

Another limitation in the application of atomic energy is that a relatively large amount of fissile material is required even for a low-power unit. This arises from the fact that a "critical size" is necessary before the chain reaction can develop. Thus, for some time to come, the minimum cost of materials for a power unit may be many thousands of pounds, and it becomes uneconomic to use atomic energy for small plants.

Another consideration is that practically every material which is incorporated in the construction of an atomic reactor becomes radioactive owing to its exposure to neutrons. For this reason, special provisions would have to be devised for maintenance.

The intense γ and neutron radiations also have an effect on the structural properties of the materials entering into the construction of the reactor. Owing to their ionizing properties, these radiations destroy the molecular bonds of many molecules. The choice of substances which can be used is, therefore, restricted to those which tend to return to their original state after intense ionization, such substances as elements and simple ionic compounds. How far even these will endure the very great irradiations resulting from large power outputs is not known, for experience is still very meagre. This effect may possibly set a limit to the power output of an atomic reactor and even to its life.

A further difficulty may be caused by the fission products, more especially in the case of the natural uranium reactor. Some of these fission products may absorb neutrons so strongly that after some time the chain reaction will be inhibited. In such a case, it would be necessary to remove the uranium, extract the fission products, and either to recharge the reactor with new metal or to recover the uranium and to replace it, adding sufficient plutonium or U236 to make it reactive.

Of necessity, all reactors manufacture fission products. At some stage or other, it will ultimately be desirable to remove them. Their disposal may prove to be an awkward problem.

Safety Precautions.

The reflection that an atomic reactor necessarily depends on a process similar to that in the atomic bomb naturally raises the question whether the control methods are adequate to eliminate all serious risks.

*This does not include the radiations from the fission products.

As I have pointed out, the essence of control is to arrange that the prompt neutrons alone cannot sustain the chain reaction, but require the help of the delayed neutrons. In this way, the relaxation time of the system is made equal to some seconds, and there is ample time for the control and safety rods to take charge of any ordinary variations in power. Danger would only arise if, by some gross accident, the multiplication factor were to increase so much that the prompt neutrons could multiply of themselves, for then the power might increase too rapidly to be controlled by the safety devices. If these fail to take charge, the reaction would probably stop itself by producing changes in the system which would increase the neutron leakage, changes such as displacements due to thermal expansion or even melting or vaporization of the metal.

In an extreme case, there might be an explosion of a low order. It is inconceivable that a reactor which has been designed for power production could explode like the bomb, for the fissile material would be dispersed and could not be assembled in a short enough time. Moreover, in the slow reactor the chain is propagated by neutrons moving with thermal velocities, so that even a deliberately uncontrolled explosion would be no more violent than one of high explosive.

Nevertheless, contingencies of this kind must be eliminated as far as possible, for the real danger arises less from the effects of the explosion itself than from the effects of the fission products which must inevitably be present in the reactor. In a high-power reactor, the fission products may be equivalent in the intensity of their radiations to many tons of radium, and if they were to escape and to be distributed by an explosion there would be serious risk to the health and lives of the population within some miles of the plant. It is possible that the heavy concrete and steel shielding of the plant might be strong enough to retain the fission products wholly within the plant, and at the worst restrict their distribution to a small area.

The problem of eliminating these dangerous contingencies is mainly one of design. Various possibilities are open, such as to limit the amount of fissile material, so that an excessive rate of reproduction is impossible, or to design the reactor so that most, if not all, possible changes, such as a rise in temperature or loss of coolant, will tend to inhibit the reaction by reducing the multiplication factor.

I have mentioned these dangers because they are a feature peculiar to atomic energy reactors, but it would be unwise to exaggerate them. The fact is that no accident of this nature has occurred, even of a minor sort, after some years of operation of these plants.

Cost of Power Derived from Atomic Energy.

As far as the *immediate* future is concerned, the application of atomic energy to the production of power is not likely to result in a net decrease of over-all costs to the community.

Owing to the difficult and tedious nature of the processes for preparing U235 or plutonium in high concentration, reactors depending on such materials for fuel will be far more costly to run than existing hydroelectric or steam power plants, and the most favorable comparison at the present time will be given by the natural uranium reactor.

Recently a U.S.A. committee has made a careful study of the costs of building and operating a natural uranium reactor to deliver 75,000 Kw., and has concluded that the over-all cost of power would be only about 25 per cent greater than for a coal-burning power plant. This estimate is based on the assumption of a high operating temperature of the uranium reactor, that is, on the performance of a plant which has not even been designed, let alone built. It does not therefore represent the present position, but the possible position in a few years' time, when research and development have provided the solution of a number of difficult technical problems. The committee's estimate is nevertheless valuable in indicating the possibilities which can already be foreseen. It is not unreasonable to expect that future development

of atomic energy will result in a material reduction of costs and perhaps make the uranium reactor a direct competitor with other power plants.

At the present moment it seems that the use of atomic power plants would be justified, on a purely economic basis only in the special circumstances I have previously mentioned, where the power needed to develop resources is either very costly or unavailable, or because of difficulties of transport.

What is needed now is intensive research and development in the technical problems which are involved in the applications of atomic energy. This will not only clarify our present somewhat vague ideas, but it may well be that quite new lines may be opened up.

In assessing the possibilities of future development it is well to remember not only that the art is in its infancy, but that the preoccupation of the war years with the military aspects of atomic energy has excluded almost completely the consideration of industrial applications. These military aspects still have, and, until some far-reaching international agreement on the control of such weapons is obtained, are bound to have, a retarding influence on peaceful developments, for the reason that the paramount need for security prevents that wide dissemination of knowledge which promotes free exchange of thought, stimulates discovery, and gives an impetus to invention and development.

Conclusion.

In this lecture I have for reasons of time omitted many features of the subject which have great interest, and some features of considerable importance. For example, I have not referred, in discussing the applications of atomic energy, to the many interesting uses of the radioactive substances which can now be produced; nor have I referred to the general economic aspect, the question of the raw materials for the exploitation of atomic energy, and the possibilities of the greater conservation of our natural resources.

In the time at my disposal I have been able to give only a broad outline of the processes concerned in the release of atomic energy and of the applications of atomic energy to the production of power for industrial purposes. I have tried to show that there are characteristic advantages and characteristic limitations in atomic power which make it in some measure a supplement to existing sources rather than a competitor of coal or oil, and which also should provide a strong incentive to push on to new developments.

At this early stage in our knowledge of these matters one cannot hope to see clearly into the future, but only to discern the probable lines of progress. Upon further investigation some lines we now have in mind may prove fruitless, but if we can be guided by the history of scientific and technical development, it is more than likely that others will give a rich reward. A few short years ago what has even now been accomplished would have been considered an idle dream.

Already a military weapon of unparalleled power has been created; enormous amounts of radioactive material have been manufactured; substances which have, owing to their inherent instability, become very rare or even completely disappeared from the cupboard of Nature have been built up by individual nuclear transmutations and collected in large quantities; and the first steps have been taken towards the development of these new energy sources for industrial application.

This new enterprise constitutes a far deeper interference with the natural course of events than anything which has been attempted hitherto, and it is a most remarkable example of the powers of physical science and engineering and of our increasing control over the processes of Nature. It is not easy at this early stage to survey in detail the consequences which may flow from this advance in the years to come, but it can hardly fail in the long run to bring about a new outlook and a new situation as regards human resources.

NOTES ON SUBMARINE DESIGN.

This article by Commodore A. I. McKee, U.S.N., covers the basic principles of submarine design. To those who have been associated with submarines the material is familiar, but to those who are not acquainted with the operation of submarines the article will be very informative. It is reproduced from the March 1947 issue of "Mechanical Engineering."

Among the engineering professions, that of submarine design is one which claims a relatively small number of engineers but one which, in the enthusiasm of its members, concedes nothing to engineers in other fields.

The submarine designer, like any other naval architect, has the problems of surface speed, hull form, stability, weight distribution, hull strength, watertight subdivision, and general arrangements; but in addition to these, he must find solutions to the problem of submergence itself, propulsion while submerged, depth control, stability while submerged and through all stages of submergence and emergence, and a real space problem.

Problem of Submergence.

Let us consider, first, the problem of submergence itself. In principle it is simple enough. We just provide some tanks and let the sea water run into them until the weight of the ship, including the water, just equals its total displacement, being careful to stop when we have just the right amount, and being careful also that the distribution of the water is such that the ship remains upright and on an even keel. On one of our modern submarines we allow about 15 seconds to take this water ballast aboard and, as it is coming in at a rate of about 2500 tons per minute, it is manifestly impossible to exercise any control of its amount or distribution at the time of flooding. So the designer must exercise the control of the amount and distribution of the water ballast, and this he does by making the tanks of such size and so locating them that when they are full, the submarine has the right amount of weight added at the right place to give it neutral buoyancy when completely submerged. These tanks are called the main ballast tanks. Since they are always open to the sea, the internal pressure is equal to the sea pressure at all depths. Their external boundaries and divisional bulkheads, therefore, may be of light construction.

Now the submerged displacement is almost a fixed quantity, varying only with the density of the sea water. This variation is so small (± 0.5 per cent) that we may neglect it during submergence and correct the trim after submergence. Since, for submergence we always take in the same amount of water, it follows that the weight and longitudinal moment of the submarine must not be permitted to vary while the ship is on the surface. The tendency for her weight to vary exists for, like any other ship, she uses fuel, lubricating oil, fresh water, stores, provisions, ammunition, and torpedoes. This is not a small matter for the total of the variable weights is in excess of 500 tons for a submarine of 1500 tons standard displacement. The design must include means by which the crew of the submarine can compensate for these variations in weight.

The fuel is the largest variable weight and, since space is always at a premium, we make the fuel tanks do double duty and serve also as compensating water tanks. The fuel system is so designed that, in order to get fuel to the engines, water must be forced into the tank and this forces the fuel out of the tank and into the fuel-oil line. This is not difficult for, as the fuel floats, we put the compensating water in at the bottom of each tank and take fuel from the top. The salt water, being about 17 per cent heavier than the fuel it displaces, overcompensates, and, in so doing, assists in compensating for the expenditure of other consumable weights.

For the complete and accurate compensation of the net variations in weights and longitudinal moments, we provide another set of tanks, called the variable ballast tanks. These tanks are so distributed that they can be partly or completely filled with salt water to compensate for any reasonable variations in

the expendable weights and their moments. Since the fuel tanks are always completely filled with a liquid, we can make the pressure in them equal to sea pressure and then build the tanks of light material. The pressure is maintained equal to sea pressure by keeping the compensating water line open to all fuel tanks at all times and providing a connection from the sea to the compensating water line. A valve in the fuel line to each tank provides all necessary control for transferring fuel.

In these days of fast airplanes there is distinct advantage in getting a submarine completely submerged and out of sight before an enemy airplane can get close enough to do some pin-point bombing. We can speed up the submerging operation by having the submarine go ahead through the water with the bow depressed; and to get the bow depressed, we deliberately submerge it first by designing the main-ballast-tank flooding holes and vents so that the flooding time for the forward tanks is only about one-half as long as for the aftertanks.

To get the main ballast tanks flooded in their allotted 15 seconds requires some special consideration. We could and, until about 4 years ago, did provide flood valves so that we could control the flooding; but when we need about 200 square feet of flooding area, this required many rather large-sized valves as well as a means for getting them opened quickly, which involved complications. When the war came along and the submariners decided not to bother with opening and closing the flood valves but just to leave them open all the time, the way was cleared to omit the valves and we now cut flooding holes in the bottoms of the tanks. The vent valves were, of course, retained and furnished all the control that was needed. By opening the vent valves the tanks can be flooded and by closing the vent valves and introducing the air into the tanks, the water is forced out the bottom.

When a submarine is running on the surface, there must be several openings in the hull, which are as follows:

(*a*) An air induction valve to supply air, about 30,000 cfm. to the engines and for ventilating the ship and the storage batteries.

(*b*) An exhaust valve for each engine that is running.

(*c*) A hatch to enable the bridge watch, 5 or 6 men, or more if the guns on the bridge are manned, to get below.

(*d*) A second hatch or door if the guns on the main deck are manned.

(*e*) An ammunition-passing scuttle if the guns are in use.

Sequence of Diving Operations.

To make a dive, certain operations are necessary;

1. Sound the diving alarm so there will be nobody who "didn't get the word."
2. Stop the engines.
3. Close the engine exhaust valves as soon as the engines are almost stopped. Indicators on these valves signal the control room that the engines have stopped.
4. Close the air induction valves.

These operations must be performed in the sequence named. Meanwhile other operations are going on as follows:

5. Open the main-ballast-tank vents.
6. Bridge watch and gun crews get below, the last man closing the hatch.
7. Close ammunition scuttle, if open.
8. Disconnect engines from shafts.
9. Go ahead on the main motors.
10. Rig out the bow planes and place at "hard dive."
11. Release compressed air to show that the ship has been sealed. (The barometer will begin to show an increase in pressure when the last opening is closed).

As the main deck will go under in about 25 seconds and as there must be no mistakes, you may be sure that the designers of the individual parts, their operating gears, controls, and indicators expend no small effort in their design and convenient arrangement, and in testing them thoroughly when it becomes

desirable to make a departure from the previous design of any one of these features.

If the reader were in command of a submarine making an approach on an enemy target and found, when he attempted to take his last look, that his diving officer had gone so deep he could not see through a periscope, he would appreciate the desirability of having not only a good diving officer, but a submarine that a good diving officer could keep at the correct depth.

The designer must provide that kind of a submarine even though it is essential to have one that will not vary by more than 6 inches from the desired depth in a smooth sea while making not more than 2 knots, a speed which a surface ship does not even look upon as steerage way. In a choppy seaway, especially with whitecaps, it is not necessary to be so particular, for the periscope would be harder to see, and risk of exposing more of the periscope or a higher speed would not be great.

Designing the Control Planes.

To make possible this desired degree of accuracy of depth control, it is conventional to provide a set of hydroplanes near the bow and another set near the stern. With this as a starting point, the designer now has only to analyze the performance of previously designed submarines which had good or indifferent, or bad depth control, decide upon the area, shape, speed of operation, method of control, exact location and method of support, and then design the planes and the operating mechanism.

In our Navy there is a further complication in the case of the bow planes as we design them to be folded flat against the sides of the ship when not in use, so they will not pound against the surface of the water. Yet the planes and their operating mechanism must be designed so that they will not be damaged if they are rigged out on the surface and do pound the surface. An attempt to determine the load so imposed by direct calculation is futile, for it would involve many assumptions which would be little better than guesses. So here again we fall back on analyses of the planes on previous submarines, including those which have failed as well as those which have not failed, and arrive at an equivalent permissible loading per square foot. It is not a small load and, for our 1500-ton submarine, it amounts to a total load of 120,000 pounds for the bow planes. The stern planes are placed just abaft the propellers, and this permits them to be made smaller than would otherwise be possible, as they are in a stream of water which is moving at a higher velocity than the water at any other place.

The bow planes are used for small changes in depth while the stern planes are used to control the inclination of the ship. For large or rapid changes in depth the stern planes are the most effective. In that case they are used to incline the ship upward or downward, and the forward motion then changes the depth.

The bow planes also serve a useful purpose which could not be accomplished by the stern planes in connection with the firing of torpedoes. If a salvo of 6 torpedoes is fired from the bow, we have suddenly removed 9 tons of weight from the bow. Its effect is to make the bow try to come to the surface. We minimize this tendency by flooding the torpedo tubes as rapidly as possible, thus regaining a part of the lost weight; but, in order to prevent broaching, the bow planes must be put at hard dive when firing is commenced and held there until full depth control is regained.

There is one more feature which is provided for depth control. It is a tank forward of amidships which is normally empty but which can be flooded quickly and which is used when it is necessary to prevent broaching or to go deep without delay. We call this tank the "negative tank" because it gives the ship negative buoyancy. The British call it the "down express," a more descriptive term. It is emptied as the ship approaches the desired depth. The negative tank may be flooded on the surface to make the submarine initially heavy, which decreases the diving time slightly. It is then emptied by compressed air as soon as the ship is submerged.

Strength of Hull Structures.

The problem of the strength of the hull differs entirely from that of a surface ship. Instead of a pressure of about 15 psi., which is the maximum to which the bottom of a surface vessel is exposed, the submarine must be designed to withstand a pressure of several hundred pounds per square inch acting on all parts of the hull. This requires a rather lengthy calculation for every frame of the ship, and careful placing of the material in the shell and frames to keep the stresses at all points near but not in excess of the acceptable limit. It also requires the most meticulous care in designing all closures and points of discontinuity for we are working with a factor of safety of 1.5, about the smallest used by any engineer. The Marbec method is used for the strength calculations, and as it is too theoretical to make the designer entirely happy, we usually make and test to destruction a reduced-size model of those parts of the ships which depart materially in shape from other models which have been tested.

Longitudinal strength is not a serious problem as it is in surface ships. Except in the largest submarines which have been built, the stresses do not approach the permissible limits.

Compartmentization is a relatively simple matter in a long cylindrical ship. Transverse bulkheads are provided to divide the ship into compartments, any one of which may be flooded without sinking the ship, provided she is not submerged at the time. One of our submarines during the war flooded a compartment while submerged. She landed on the bottom almost immediately but the crew was able to bring her to the surface and to the nearest friendly port, over 2000 miles. There have been several cases where a compartment has been flooded while a submarine was on the surface, and the bulkheads saved the ship from sinking. The design of the bulkheads, because of the pressure involved and of the necessity for keeping the weight within reasonable limits, is based upon formulas derived from many tests of small-scale bulkheads rather than on the usual beam formulas.

The most difficult problem has been the design of a door which must be able to withstand the required pressure in either direction. We had a very good test of one submarine door in 1939 when the *Squalus* sank. This door was exposed to a pressure of 105 psi. in the direction which tended to unseat it, and the total leakage in the 113 days before the ship was raised was only a few gallons. Since that time it has been necessary to change the design of the doors to make them suitable for more than twice this pressure. As now being used, the door can be closed and secured in 8 seconds by one man against a total force of 140,000 pounds.

Stability Calculations.

Stability is always a matter of concern to the naval architect. If he is working on the design of a surface ship, he calculates with considerable accuracy the heights of the center of gravity and the center of buoyancy in the various conditions of loading he expects the ship to encounter and then adjusts the beam to give him the desired metacentric height. This statement makes the process sound simpler than it really is, for if his original estimate of the beam was not a reasonably good one, he might find it necessary to alter the lines to such an extent that he must recalculate the position of his centers of buoyancy and of weight. However, he still is able to obtain the desired stability characteristics by choosing a favorable breadth at the water line.

On the other hand, the submarine designer must obtain satisfactory stability with the ship submerged. Then there is no water line and a change in the beam has no effect on stability. Furthermore, the parts of the submarine which are not fully flooded must be essentially circular in section so they will withstand the required pressures. So the only factor available for him to work on to get the desired stability when submerged is the position of the center of gravity. Nobody has ever succeeded in getting too much stability submerged, so all efforts are directed toward keeping the heavy components as low as practicable. Even the lighter items such as pipe lines and electric

cables are placed as low as the available space permits. Those items which are too bulky or which must be readily accessible to the operating stations are screened carefully to be sure thay have been made as light as they can be. This latter is very important and must be borne in mind during the development of all the working plans.

Not many years ago one of our submarine design yards was rather hard-pressed in the drafting room to get the plans prepared by the time they were needed and relaxed somewhat its efforts to keep the structure and fittings near the top of the ship as light as might have been possible. As a result, the stability of the ships of that class was less than the designed stability and barely above the acceptable minimum. Later in their lives these ships could not be given all the alterations which were found desirable under war conditions and, before the close of the war, were withdrawn from combat and used for training.

This incident brought forcibly to the attention of that yard the necessity for meticulous care in the design of each part, and the saving of weight was a serious consideration during all stages of the design of the following class. That this care paid dividends was well established by the fact that the actual weight of this class was about 100 tons less than the original designed weights. As previously stated, a given submarine must be kept at a constant displacement, so it was necessary to add 100 tons of ballast before these submarines could operate. This ballast could be placed at the bottom of the ship where it would lower the center of gravity and increase the stability. The stability exceeded the requirements by a considerable amount, and 100 tons seems like a lot of extra ballast.

This margin of weight and stability was obtained at the most opportune moment, just before the 1940 building program. All of the submarines built during the war were built to this design with slight modifications from time to time. Whenever a new device was invented or developed that would increase the effectiveness of the submarine, and they nearly always meant an increase in weight, we had the weight available merely by removing some of the ballast. Never during the war was there any concern about a submarine being deficient in stability or overweight. Nor was it ever necessary to decline to make a desirable change in the design because we could not tolerate the additional weight. Continued attention to weight in the detail design maintained this very satisfactory position even until the war ended.

All of the foregoing considerations pertain to the stability when submerged. It is still necessary to provide satisfactory stability on the surface, and this is accomplished in the same way it is done on any other surface ship.

Almost Constant Change in Details.

In 1940, when orders were placed for a fairly large number of submarines, the designers felt that they had a very satisfactory design which was ready for production in quantity. Yet, as the war progressed, it became more and more apparent that what they actually had was a very satisfactory starting point for the continuous development of the design.

Mention has been made of the fact that changes were made during the war. There were no basic changes, for the shape of the hull and the same general arrangement were used for all submarines built during the war. However, the author finds it difficult to think of a single part that did not undergo at least one change in design. Of the hundreds of changes, some of the principal ones may be mentioned as follows:

Two 5-in. and two 40-mm. guns were substituted for one 3-in. and two 50-caliber machine guns.

The crew was increased from 54 to 70 and the additional required berths and lockers were added.

The number of officers was doubled and the required accommodations were provided.

Four additional torpedoes were provided.

The fuel capacity was increased by 20 per cent.

Three radar sets were added and each of these was changed at least once to keep up with the rapid developments.

The strength of the hull and its resistance to underwater explosions was greatly increased. This required new designs for all fittings subject to pressure, as well as for the entire structure of the ship.

The main motors and their controls were radically changed.

The diving time was reduced by one-third.

The capacity of the air-conditioning plant was increased by 50 per cent.

The reasons for some of these changes are obvious, but the consideration which caused the most numerous changes of individual parts was that of the production of underwater noise. This required the careful study of every moving part, and eventually, every such part was changed to make it less noisy. If ever a designer was repaid for his efforts, this was the time, for the amount of noise produced by a submarine at the end of the war was only 1 per cent of that produced at the beginning of the war.

No discussion of the subject of submarine design would be complete without mention of the part played by the operating personnel. Every designer knows that his most valuable source of information is the criticism of his customers. Unlike most customers, however, the submariners know their ships thoroughly, both in principle and in detail, how every part works, and how to fix it when it doesn't work properly. With such a background it is not surprising that their criticism was almost invariably constructive. Without such constructive criticism, it is difficult to believe that the submarine could have been developed into a weapon as effective as it has proved to be.

ROLLER BEARINGS IN STERN TUBES.

This interesting article from the August 1946 issue of "Motor Ship" gives a brief resume of experience to date with the use of roller bearings in place of the conventional lignum vitae or rubber stern tube bearings.

One of the most difficult positions in which bearings are required to operate on board ship is in the stern tube. Also it is one of the bearing applications in which tradition has resisted change for the longest time. For generations, a lignum vitae—lined tube was the universally accepted standard type of stern tube used on large ships, while on small vessels either lignum vitae or some sort of low friction material was used to provide bearing surfaces for propeller shafts.

Sea water was depended upon for lubrication, the inboard end of the tube being provided with a stuffing box, usually of the plain flax-packed type, to prevent leakage of water into the hull. In most cases this stuffing box would be slacked off enough to permit slight leakage, thus insuring a flow of water through the bearings. Naturally any sediment or foreign matter in the floatation water found its way into the bearings with the water, wear of the bearings was the expected thing and their renewal at frequent intervals was a routine maintenance job.

Owing to the heavy wear of plain stern tube bearings, the propeller shaft is subjected to continuous bending and twisting stresses, and the resulting fatigue sometimes causes fracture of the shaft. Fracture also may occur as a result of corrosion due to penetration of sea water between the shaft and the bronze or brass liner shrunk on it.

Frictional loss, resulting in waste of engine power, is appreciable with this type of bearing. In connection with the tests made in Europe, before the war, to determine the friction losses in line shaft bearings, tests also were made on the stern tube bearings. For these tests the thermal method was used. By means of Btu. calculations based on measurements of the temperature and amount of the incoming and outgoing water it was determined that the friction loss in stern tubes using plain bearings is about two per cent.

Because of the considerations discussed in the foregoing, it became apparent that the application of self-aligning, anti-friction roller bearings to stern tubes

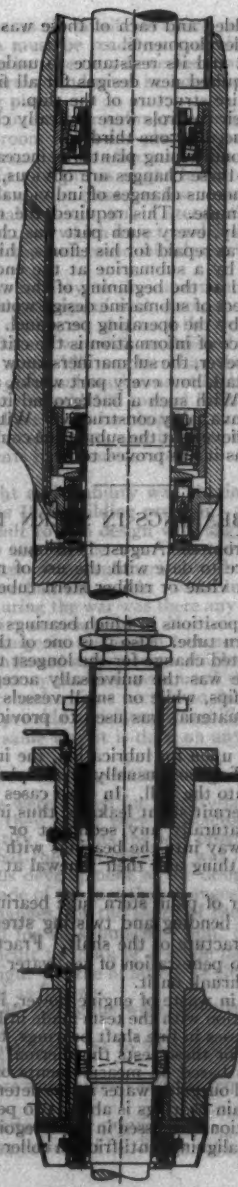


Figure 1. Early applications of the SKF spherical roller bearing. A-A, left, in the first installation. B-B, right, the installation in the Wuppertal.

would be very advantageous. Accordingly, the first installation of such bearings was made in 1934 in a small oil tanker operating in a European harbor where the water is particularly muddy. Two SKF spherical roller bearings were installed in the stern tube, arranged to operate under slight oil pressure and the ends of the tube were sealed by flexible leather seals and a Cedervall stuffing box. Details of this first application are shown in Figure 1-A.

The next step in the development was the application of this type of bearing in the stern tubes of large, ocean going vessels. The first ship of this kind to be so outfitted was the German 6737-ton motorship *Wuppertal*. Two SKF spherical roller bearings were used in each stern tube, with spring-loaded graphite rings for sealing. The general arrangement of the bearing application is shown in Figure 1-B.

Although some trouble was experienced in securing a good seal, the bearings proved highly satisfactory and the Hamburg-American Line, owners of the *Wuppertal*, proceeded to equip the stern tube of nine more large motorships with SKF spherical roller bearings. The Diesel-electric liner *Robert Ley*, of the German Worlk Front was similarly equipped in 1937.

Despite the good results obtained with roller bearing equipped stern tubes in Europe, little interest was shown in such applications in the United States until 1939 when the U. S. Coast Guard became actively interested and began equipping some of its smaller boats with the SKF stern tube design. The results obtained led to the extension of such applications to larger ships. At time of writing, there are nearly 100 Coast Guard vessels so equipped, as shown by the list in Table 1.

TABLE 1.—COAST GUARD VESSELS EQUIPPED WITH ROLLER BEARINGS.

No.	Length	Class
12	65 ft.	*CG63300* (Harbor)
1	80 "	*Lantana* (Riverboat)
1	113 "	*Forsythia* (Riverboat)
4	113 "	*Cosmos* (Riverboat)
9	110 "	*Apalachee* (Tug)
10	180 "	*Cactus* (Ice Breaker)
1	225 "	*Storis* (Ice Breaker)
13	255 "	*Mendota* (Cruising Cutter)

In addition, the U. S. Army has installed stern tube roller bearings in 56 tugs and the Maritime Commission has fitted them in 26 tankers. A typical installation arrangement, as used in the *Cactus* class cutters is shown in Figure 2.

In the various installations, two types of application are used. In one, the thrust block is located between the propeller shaft and engine, in which case the roller bearings in the tube does not take the thrust and are of the ordinary radial type. In the other, the roller bearing in the forward end of the tube serves as a thrust bearing and carries some radial load plus the load due to propeller thrust.

To meet this latter condition, SKF developed a type of roller bearing in which the angle between the axes of the shaft and the rollers is increased to approximately 45 degrees as shown in Figure 2.

In conformity with the experience of the German ships previously referred to, the Coast Guard found that the roller bearings themselves were trouble free but difficulty was experienced in maintaining an adequate seal of the stern tube. This caused no trouble with the bearings because the stern tube is filled at all times with oil under a pressure greater than the pressure of the outside water, but it did involve, in the earlier installations, a considerable loss of oil.

This trouble disappeared with the adoption of the Syntron seal, of which some 64 sets have been installed in Coast Guard vessels at the time of writing. The arrangement of this seal and its relation to the roller bearing is also shown in Figure 2. Here it may be seen that the sealing is effected by metal

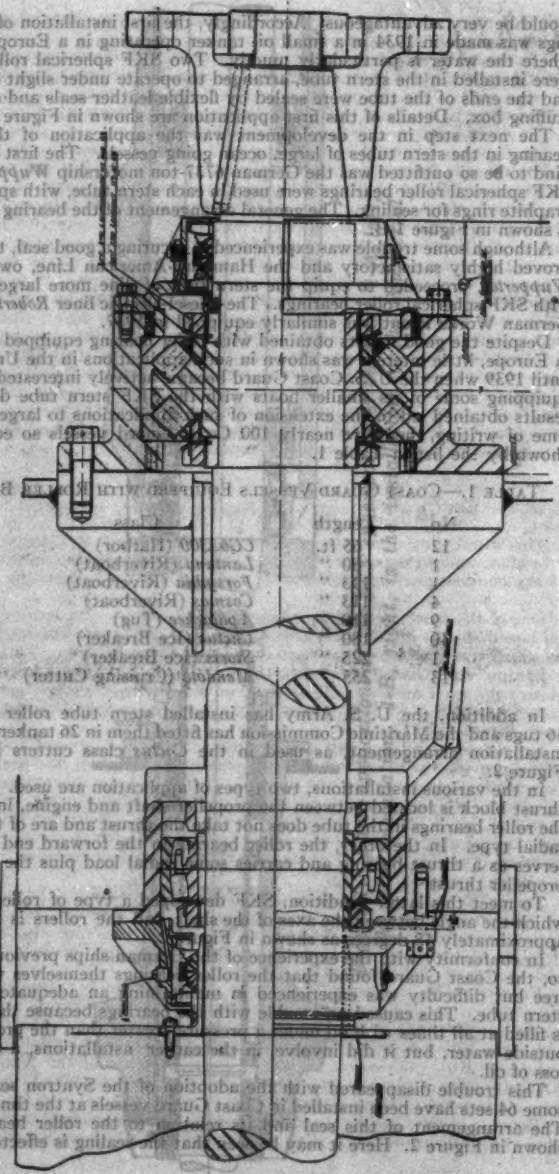


Figure 2. The latest Cactus class cutter installation showing the use of the radial and thrust type bearings and the Syntron seals.

rings that rotate with the shaft and are pressed against stationary graphite rings by springs. The seal is at all times under oil pressure and the design is such that as the fluid pressure increases the pressure on the sealing faces automatically increases.

The Coast Guard reports that such trouble as has been experienced with the roller bearings has not been due to the bearings themselves but has been caused by dirt and metal chips being left in the lubricating oil lines by shipyard workmen. This was a very common experience during wartime, when thousands of relatively inexperienced workmen were working under high pressure. It is essential for the success of stern tube roller bearings, as well as any other roller bearing application, that the lubricating system be thoroughly cleaned before using. With a clean system and with the bearings operating submerged in oil, long life is assured. The bearings are not critical as to the type of oil used. Mineral oil of 30-50 S.A.E. viscosity is entirely suitable. This positive method of continuous lubrication of all moving parts in the stern tube is a very attractive feature.

Another precaution that should be observed in connection with installations in which the inboard roller bearing serves as a thrust bearing, is to provide some form of coupling between engine and propeller shaft that will allow a certain amount of axial freedom. Otherwise, the expansion of the engine bed and shafting when the engine warms up will overload and destroy the engine stabilizer bearings as any axial movement must of necessity be taken up by crankshaft movement because of the very slight axial freedom of the thrust bearing.

A striking demonstration of the ability of roller bearings to absorb shock without injury is found in the case of the *Lantana*, a Coast Guard river-type cutter propelled by triple screws and equipped with SKF spherical roller bearings in all stern tubes. As the result of an encounter with ice, all three propellers were severely damaged, two propellers being left with only a piece of one blade on each while the third propeller had left a short piece of each blade. When the vessel was docked for examination it was found that despite the heavy shocks of the blows that snapped the propeller blades like straws, the roller bearings in the stern tubes showed not the slightest sign of injury and required no repair. It should be noted that the *Lantana's* stern tubes extend out to the struts and the outboard roller bearing is right next to the propeller.

It may be stated that roller bearings in stern tubes, as compared to plain bearings, appear to offer a definite saving in operation and maintenance costs, due to these factors.

1. Lower installation cost due to greater reduced overall machining requirements, such as: depth of stern eye bore being approximately one-fifth (1/5) that required for friction type bearings, elimination of fine shaft machining for fitting bronze liners with subsequent machining of liner outside diameter. The SKF design employs a standard bearing mountable on American Standard commercial finished shafting with no additional machining required.

2. Substantial saving in power and fuel.

3. Reduced maintenance costs through elimination of shaft and bearing wear with the attendant need for periodical shaft and bearing replacement, by removing all rubbing contact with the shaft. This eliminates possible stress localization and likelihood of shaft fractures.

DEHUMIDIFICATION PROTECTS U. S. NAVY'S INACTIVE FLEET.

This article by Captain T. H. Urdahl, U.S.N.R., and Commander E. R. Queer, U.S.N.R., who, in their duties in the Air-Conditioning Section of the Bureau of Ships, have been largely responsible for the development of the Navy's dehumidification procedures, will be of interest to all hands, whether they are engaged in inactive fleet work or not. The paper is reprinted from the March 1946 issue of "Heating, Piping and Air-Conditioning."

With the end of World War II, preservation measures to implement the U. S. Navy's "Keep the Fleet" program are not only well defined, but are already being applied.

At the end of World War I, the same factors which make up the problems of preservation were as well known as they are today—but the "engineering link" between desirability and practicability had not been forged. The preservation methods employed then comprised the application of materials readily at hand. These consisted principally of red lead and grease, which provided a quality for preservation far inferior to similar materials available today. Such ineffective and costly methods have served as an ample reminder of the necessity for a more adequate means of protecting our naval vessels against the ravages of atmospheric corrosion.

Today, approximately 2700 ships of combatant and noncombatant types are being protected by employing scientific means of dehumidification, painting, thin film rust preventive compound application, and tight packaging. The speed at which the ship so preserved can be returned to an active status has been a primary consideration in the selection of preservation methods. Through these procedures, both quick and inexpensive, it is certain that our Navy will remain in an excellent condition of readiness for many years.

The problem presented in the preservation of a ship involves the following factors:

(1) Moisture and atmospheric conditions cause corrosion of metals, mold, mildew, and general deterioration of equipment and materials aboard.

(2) The removal of equipment and materials for storage ashore is expensive, and storage offers no protection against deterioration unless adequate treatment is applied.

(3) Adequately closing a ship's hull provides an excellent vapor and water barrier and quantities of atmospheric moisture admitted by breathing and infiltration can thus be controlled.

(4) Preservation by means of coatings alone is not sufficient.

Ship Is Storehouse for Its Equipment.

The solution most immediately apparent in analyzing these factors is that of using the ship as a storehouse for all of its own required equipment. The ship must be made as tight as economically practicable against the admission of outside air and moisture. The atmosphere within should then be maintained at a relative humidity of 30 per cent or less, since at this point, it has been determined that general deterioration is inhibited for an indefinite period.

The practicability of obtaining this solution to the problem was dependent upon the development and manufacture of equipment which could maintain the desired low humidity condition under the entire range of weather conditions prevailing throughout the year in any of the 14 berthing areas variously dispersed about the continental United States. Also basic to the matter of obtaining adequate equipment was quantitative data concerning the moisture loads to be removed, in order to arrive at economical unit sizes to cover the space requirements of various types of vessels.

A great deal of thought has been given to this and similar preservation problems over the past 20 years. Some development work had been carried on toward providing equipment of a satisfactory type to accomplish the desired control of humidity just prior to World War II, at which time the Navy's development efforts were diverted to the essentially higher priority of active fleet equipment.

However, the past work had formed a basis for recent developments for future requirements. The dehumidification of vessels for cargo preservation had been successfully accomplished by one company, who pioneered the idea. All of this background—including that with cargo vessels—contributed to pointing out the many difficulties and variables that such a problem involves, and (by no means least) showed the necessity for the development of more practical and efficient dehumidifying equipment.

The present program—and the equipment which is basic to its success—was begun, evolved, and completed in the last two years, with the assistance

and advice of many manufacturers and consultants whose various contributions were carefully screened, considered, and finally molded by the Bureau of Ships into a composite idea upon which the Navy was able to proceed. Test installations were made in various localities on various types of inactive vessels for the purpose of determining the practicability of these preservation measures. Dehumidifying machines were designed, tested, and re-designed to obtain the desired efficiency and ruggedness of construction for long life with minimum attention.

The results have produced dehumidifying machines employing solid chemical desiccants and a method of control of these machines combining the features of averaging, recording, and indicating. In addition to these, there are other means of moisture removal with static desiccants, methods of packaging deck equipment and ordnance, and—under certain conditions—the application of preservatives on bright steel surfaces. With the equipment now being installed, the ship virtually becomes a dry storage warehouse and the necessity for additional storage ashore is eliminated.

Orders to "Inactive Fleet."

Upon receipt of orders to the "inactive fleet," the ship proceeds immediately with preservation measures. Upon reporting, all urgent repairs are accomplished and the ship is drydocked to apply new antifouling paint and to have other essential underwater work undertaken. There is an immediate one-third reduction of the wartime complement by detaching the special, radar, communications, and gunnery ratings.

Preliminary preservation measures, consisting of cleaning and drying the ship's hull and machinery, are accomplished and thin film rust preventive compounds are applied. The equipment is ready for immediate use without the removal of preservatives. Although there are few vermin, germs, and insects on naval vessels, prior to final closure the ship is completely fumigated.

During these initial preparations, the dehumidification equipment is installed according to plan and made ready to operate. The last stage before the ship goes under dehumidification is to seal the envelope from the sea and the weather and to open doors and hatches within the ship, as needed for the dry air flow. However, the watertight integrity of the ship is maintained at all times. Although it is desirable to make the topside as tight as practicable, it is not essential that the ship be made pressure tight to secure good economy of operation; watertightness, however, is absolutely imperative but easy of attainment.

Dynamic and Static Dehumidification.

Dehumidification is accomplished both dynamically and statically.

Dynamic dehumidification consists of forcing the ship's air through an automatically controlled and reactivated chemical desiccant machine connected to a distribution system. The fire mains are drained and, since they extend throughout the ship, they provide an excellent means for distributing the small quantities of dry air and return flow is controlled by choice of closure of access openings. (Figure 1 shows a typical system.) Fire protection is provided from the shore and fire boats. The distribution does not have to be positive to all spaces, for it has been ascertained by test that diffusion will provide satisfactory distribution for inner bottoms, appending tanks, and voids.

Static dehumidification is obtained by placing metal containers of desiccants in closed voids, tanks, and metal packages. This system is used only in spaces that cannot be easily reached dynamically or where the watertight integrity of the ship would be violated through opening doors, hatches, and manholes. Only about 5 per cent of the overall inactive fleet dehumidification will be accomplished statically.

The process of dehumidification is divided into two stages: initial drying and maintenance drying. During the initial drying period, all free water is removed from the bilges; steam, water, and drainage piping; and boilers and machinery. Portable dynamic machines are used to pre-dry. After the pre-

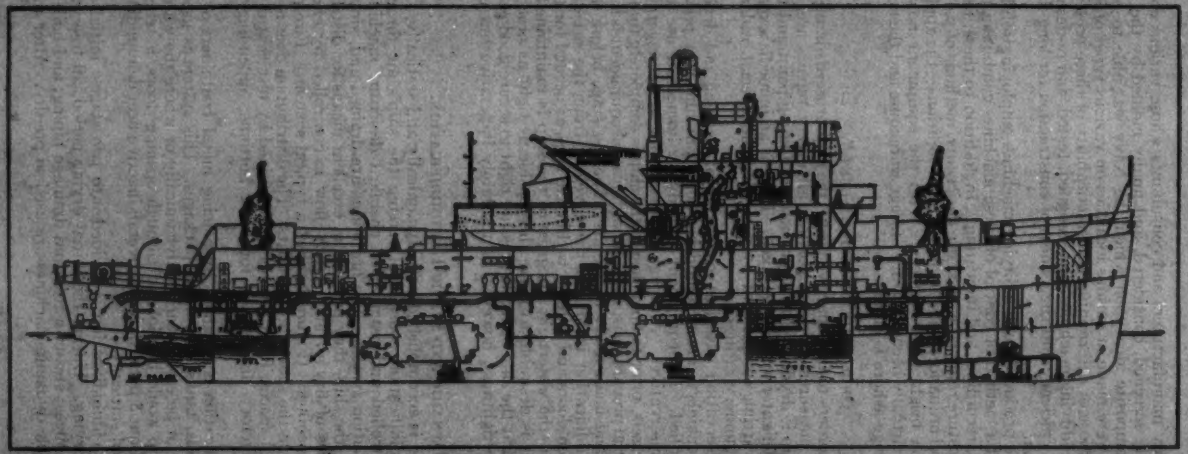


Fig. 1—Typical installation of dynamic dehumidification for protecting a ship. The fire mains provide a means for distributing the small quantities of dry air, fire protection being provided from the shore and from fire boats. A controller-recorder of unique design is connected to eight stations for sensing the relative humidity in spaces throughout the ship

drying is accomplished and the main dynamic system put into operation, the moisture load is composed of air-entrained vapor and a considerable quantity of water vapor adsorbed in the painted surfaces, lines, mattresses, etc.

In initial drying the machines will operate continuously for four to six weeks, drawing the adsorbed water from the surfaces while the space humidity is reduced to 30 per cent. During the maintenance drying stage the moisture load is reduced chiefly to breathing caused by diurnal changes of temperature, infiltration, and such topside and underwater leakage that may inadvertently occur. Such leaks must be found early and caulked, otherwise the dehumidification machine becomes "a costly bilge pump."

The Dehumidifying Equipment.

For the most economical use of the equipment, the machine capacity should be installed to take care of that amount of ship's space to provide 12 hours per day of operation during the maintenance stage. Since breathing is the major load, the machines operate principally at night and the early morning hours. The relative humidity decreases during the day because of rising temperature, and rises at night because of falling temperature and breathing of weather air.

Dynamic dehumidifiers.—The dynamic machines used for the Navy's inactive fleet are the dual bed type, and desiccants employed are silica gel and activated alumina. The general arrangements of the machine circuits are shown in Figure 2. Humid air is drawn from the ship and passed through the adsorbing desiccant bed. A high pressure fan returns the air to the ship through the distribution system. A second air circuit is provided for the reactivation of the exhausted desiccant bed. In this, weather air is heated with electrical elements situated either directly in the desiccant or by strip heaters in the air stream. The effluent reactivation air is discharged overboard to the weather. The control of the cycles (switching beds) is accomplished automatically with a timer or a thermostat.

Most of the requirements will be taken care of with three standard sizes of machines. A summary of the specifications for the dehumidifier units is given in Table 1.

Table 1.—Summary of Specifications for Dehumidifier Units.

	Package	Small Size	Large Size
Adsorption air, cfm.	20	150	500
Connected load, kw.	1	3	5
Static pressure external to machine, inches water	⅛	3	5–¼
Adsorption capacity, lb. per hr.:			
95 F., 35% relative humidity	5.4*	2.6	7.5
70 F., 35% relative humidity	5.0*	2.0	5.5
40 F., 35% relative humidity	2.9*		2.5
Reactivation economy, kw. hr. per lb. of water:			
95 F., 35% relative humidity	0.80	0.90	0.93
70 F., 35% relative humidity	0.85	1.00	1.00
40 F., 35% relative humidity	1.40		1.25

* Lb. per day.

Package dehumidifier.—The package dehumidifier is a single bed type developed for drying metal packages over mounts, guns, and searchlights, and it is also available for isolated compartments to which it is uneconomical to extend the dynamic system from a ship zone. The unit is also capable of handling small vessels, such as landing craft. The cycle on this unit is automatic, consisting of 2 hr. and 25 min. adsorption, and 35 min. reactivation. The package dehumidifier—with the proper reactivation air connections to the weather—can be substituted for the portable dehumidifier mentioned hereafter.

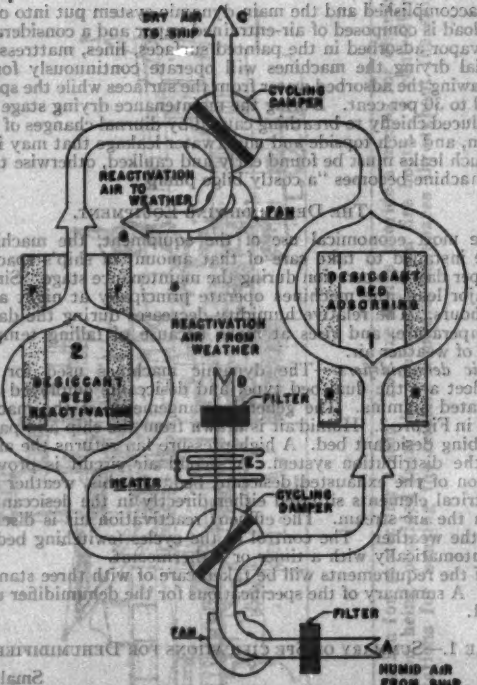


Fig. 2—The dynamic dehumidification machines used in the Navy's "keep the fleet" program are of the dual bed type, as shown in this diagram of the general arrangement. Humid air is drawn from the ship and passed through the adsorbing desiccant bed, and a second air circuit is provided for reactivating exhausted desiccant bed (silica gel or activated alumina).

Portable dehumidifiers.—The portable dehumidifiers are used for initial drying of compartments, freshwater tanks, piping, boilers, etc. They have been found useful for initial drying of spaces that are to be treated statically and before and after painting. The unit consists of a container called a "desiccanister" filled with 40 pounds of silica gel. To this is attached a fan with a heater unit. Air from the compartment to be dried is circulated through the desiccanister. In drying piping, the ship or weather air is predried and forced through the pipes. When the desiccant is exhausted three indicator gel ports show a pink color. The desiccanister is reactivated by removing the unit from the compartment to an undried portion of the ship or to the weather and using the built in electrical element to heat the air passing through the desiccant, until the indicator ports again show blue. Each unit is supplied with two desiccanisters.

"Desicans."—The static dehumidification is accomplished by placing approximately 5¼ pounds of silica gel in a permanent aluminum container with perforated surfaces. Each container is provided with a port containing indicator silica gel. These units are called "desicans" and come packed eight or nine in a metal drum carrying case.

Breathers.—Fuel tanks will contain oil or be coated with oil as a means of protection. Diurnal changes in temperature will cause breathing and, to prevent an accumulation of condensed atmospheric moisture in the tanks, breathers are provided on the weather vents. The breather for fuel tanks contains an inexpensive desiccant that can be discarded. Desiccants will adsorb oil vapors which—in addition to producing a hazard during reactivation—will carbonize and damage the desiccant. Breathers may also be used on metal packages under static dehumidification. Some thought is being given to the development of a solar reactivated breather.

Reactivator.—An automatic temperature controlled electric oven is provided to reactivate the desicans and those breathers which may be used on metal packaging. The air is heated to 325 F. and circulated with a fan.

How Humidity Is Controlled.

The relative humidity in the dynamic zones is controlled and recorded by a controller-recorder of unique design. This instrument is a combined development of the Bureau of Ships Air Conditioning Section and an instrument manufacturer.

The instrument consists of a main control and recording station to which are connected eight stations for sensing the relative humidity; in addition, each sensing station contains a temperature element. A record of the temperature and humidity is printed in arabic numbers on an adding machine strip paper once every 15 minutes continuously or once every 12 hours as desired. The identifying station number and the time are also printed.

For control purposes the instrument continuously averages the relative humidity at the eight sensing stations. If the average ship's relative humidity rises above, say, 33 per cent, the dehumidifier will be turned on and continue to operate until the average is worked down to, say, 27 per cent. The differential is adjustable so as to prevent short-cycling of the dehumidifier.

The controller-recorder assists in balancing the distribution of dry air in the ship. If the humidity at a particular station is running above 35 per cent relative humidity, the air control valve (a fire main valve) in that subdivision of the ship is opened to allow an additional amount of dry air into that subdivision. Conversely, if another subdivision is below 25 per cent relative humidity, then the control valve for that section can be adjusted accordingly. With the aid of a simple, direct reading, air flow meter developed by the Bureau of Ships these adjustments can be made by an enlisted man serving on watch. In the event of persistently high values of humidity, an inspection must be made to determine the source of moisture and corrective measures taken. This instrument will contribute much toward reducing the cost of maintaining the inactive fleet in future years.

In conclusion, it can be said that dehumidification, as carried out by the above procedure, is an economical means of preserving a costly investment in valuable ships. The installed equipment cost is less than 1 cent per cubic foot of ship's volume in the majority of cases. The power cost will run well below 15 cents per 100,000 cubic feet of volume per day with power at 1 cent per Kwhr.

Dehumidification Protects a Costly Investment.

The attendant dehumidification power cost for a destroyer having a volume of approximately 250,000 cubic feet will be about $110 per year on a $7,000,000 investment. A 35,000 ton battleship, costing from 90 to 100 million dollars, would have an attendant dehumidification power cost of $1550. Therefore, it is obvious that the economy of dehumidification as a preservation measure is attractive to the taxpayer. In addition, preservation with dry air will provide an excellent means of preserving America's seapower in a state of readiness for any and all emergencies.

RUSTING CHARACTERISTICS OF TURBINE LUBRICATING OILS.

This interesting summary of the investigations made to eliminate rusting characteristics from Turbine Lubricating Oils is reprinted from the October 1946 issue of "Mechanical Engineering." It was prepared by Mr. W. P. Kuebler of the Westinghouse Electric Company.

Usually, when we discuss the characteristics of turbine oils, we consider oxidation, emulsion, life, etc., all desirable and positive in nature, but in this paper we will concern ourselves with a negative characteristic, that of rusting, for one usually associates oil with the prevention of rusting.

The tremendous difference in design between large and small turbines and between the old and newer-type units is well known. The complex design of the modern turbine oiling system renders dismantling for cleaning difficult and expensive. The higher pressures, with their attendant higher temperatures, and the extremely intricate and closely fitted parts in the control apparatus of the modern turbine could not tolerate the use of the older-type normally refined oils. Thus with the advance in turbine design there has been an advance in the development of the lubricating oils.

If it were possible to stop and clean a turbine at short intervals, the turbine oil of former years might still be used successfully. However, with a modern turbine called upon to operate continuously for a year or longer without stopping for cleaning or adjustment, the use of an oil with desirable long-life features becomes of extreme importance.

In the case of turbine oil of 15 or 20 years ago, it was almost universally agreed that, when the neutralization number reached 0.50, the oil should be removed. During its life, it had usually been "sweetened" by the addition of new oil from time to time. We know that these older oils deteriorated readily in comparison with the life of the modern oil, that the products of deterioration resulted in heavy sludges and deposition of "varnishes" on the metal surfaces, and that the thickness of these deposits increased until they would eventually interfere with the normal lubrication of the turbine, in that clearances were markedly reduced, particularly where close clearances exist as in the case of the governing apparatus.

Certainly, no turbine-oil user would want to go back to the older types of oil; in fact, it is questionable if we would care to use them in the modern turbine. We cannot recall that the turbine manufacturers told the refiners that they must "build" a better oil, or that the turbine builder and the refiner met and decided to build better turbines and oils. On the other hand, improved turbines and turbine oils were the result of modern research and development. As a representative of a turbine manufacturer, the author cannot but state that the refiners most certainly have done their part in developing and supplying suitable, stable, long-life lubricants for the modern turbines.

Development of Modern Turbine Oils.

The development of the modern stable turbine oil was not immediate but resulted from continued research during a transition period of some 15 to 20 years, combined with the advent of solvent and other improved methods of refining.

In general, each improvement in refining (improvements in removing undesirable components) resulted in definitely improved oil in terms of prolonged operating life, resistance to sludging and normal breakdown, with the elimination of the deposition of "varnishes" previously mentioned.

In this discussion of rusting characteristics, we must pause to touch on the matter of moisture in turbine lubricating systems. To exclude moisture entirely from turbine lubricating systems is practically impossible. The presence of moisture aggravates emulsification, sludging, and corrosion from built-up acid content in the oil. With the modern turbine oil, these conditions have been eliminated to a very great extent, but in their place we encounter corrosion and rusting when water is present.

The nonrusting characteristics of oils are dependent upon their ability preferentially to "wet" the surface of the metal in the presence of water. In

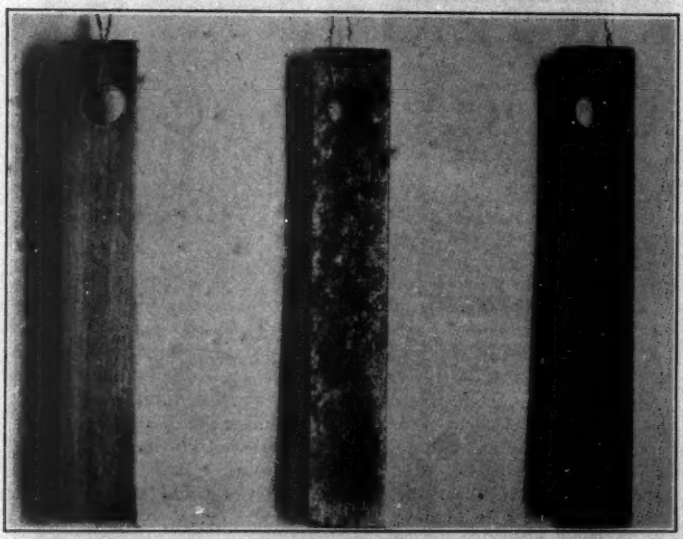


FIGURE 1.—STEEL CORROSION TEST PIECES.
(Left to right: No. 6561 light turbine test oil, plain, 384 hr.; No. 6561 light turbine test oil, 1 per cent water added, 384 hr.; oil from DeLaval gear case, 264 hr.)

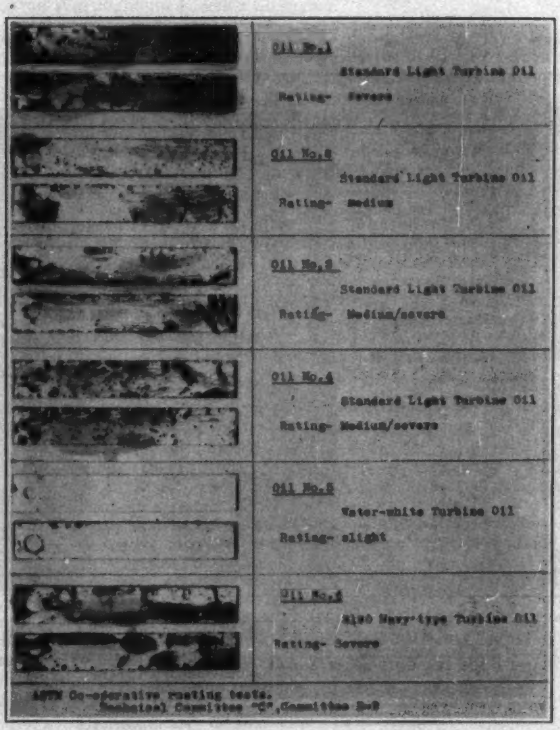


FIGURE 2.—TEST METHOD OF AUTHOR'S COMPANY AS SUBMITTED IN A.S.T.M. CO-OPERATIVE RUSTING TESTS.

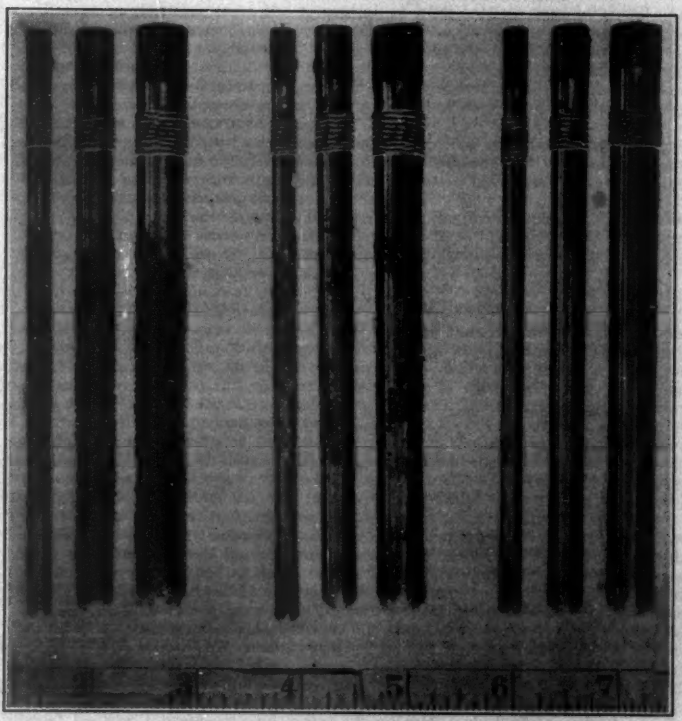
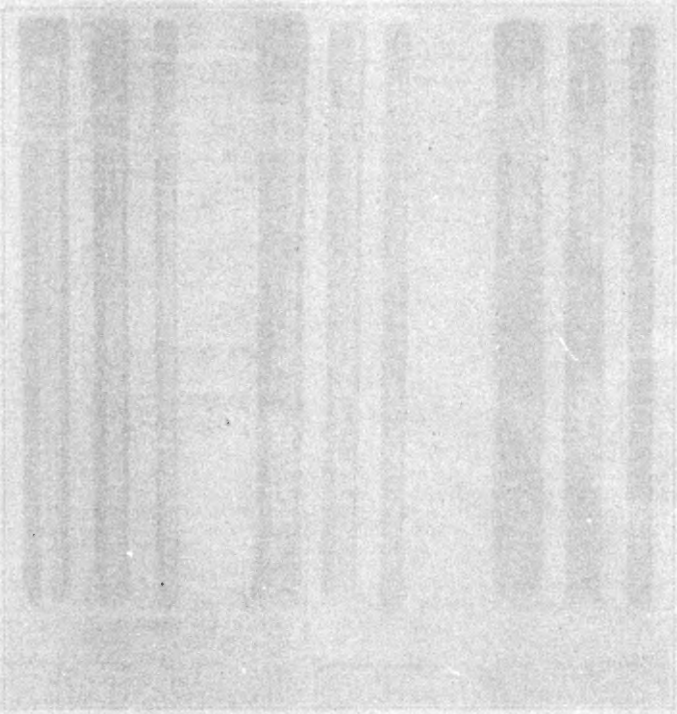


FIGURE 3.—RESULTS OF RUSTING WITH TURBINE OILS ON ROUND SPECIMENS.



the older types of oil this wetting ability was in general inherent in the oil; however, it appears that the components in the oil which provided for this wetting ability were also those which contributed to the earlier deterioration mentioned. Thus through their removal oil life was improved, but the wetting ability was decreased, and as a result rusting was encountered.

Corrosion resulting from the formation of high acid content in an oil and the subsequent attack of metallic surfaces and the formation of metallic soaps has been practically eliminated. The corrosion or rusting when water is present in the modern oil is of a different nature and began to be encountered some 10 years ago with the advent of the increase in the use of highly refined oils. Corrosion was so severe in many cases that expensive shutdowns were necessary in order to recondition.

Figure 1 shows three steel corrosion test pieces run early in 1937 and illustrates the type of corrosion encountered. While the test was not a rusting test in the strict sense, rusting was obtained as a "by-product" and pointed the way to future investigations.

It is this type of corrosion that occurred with the modern oils, and we would like to outline the developments leading to the "discovery" that modern highly refined oils allowed rust to form when moisture was present in the oil, particularly in a new system.

Early History of Rusting Problem.

For several years prior to April, 1937, we had been receiving reports from the field of lubrication difficulties from rusting, and it appeared that they could all be attributed to solvent-refined oils. Unfortunately, we were not afforded the opportunity to examine the oils in question or the residues. For some years up to that time, the number of instances brought to our attention, wherein turbine oil had sludged, oxidized, or broken down and caused bearing and other lubrication difficulties (other than rusting), had been reduced to a minimum. Rusting had occurred in both old and new units. In the older units, mechanical construction was such that rusting, while most undesirable, did not interfere materially with control; however, in the newer type control systems, it materially affected operation.

Rusting had been the subject of a number of discussions with representatives of refiners, but our problems appeared to have been lightly dismissed.

Rusting, when using the more modern oils, was encountered on our tests floors. Admittedly we did not immediately recognize its source but tended to place the blame on improper shop practices, for how could an oil allow rust to form? Samples of residues found in the oiling system were identified principally as the black magnetic oxide of iron ordinarily known as mill scale. Thus, we took our shopmen to task for not cleaning parts before assembly, for this oxide forms only at temperatures of 600 F. or above, and we reasoned it must have been in the piping or other parts. Later it was definitely established by our laboratory and other investigators that the product of oil-water corrosion on steel was the black oxide.

Then, in September, 1936, we were asked to investigate a report that some sort of an alkaline solution was being circulated in turbines in the field before oil was placed therein, to "kill the acid" in the steel, thus preventing future rusting of the parts. There is, of course, no acid in steel and we believe someone heard of acid open-hearth steel, a term derived from the type of furnace lining, and became confused in his reasoning. We were unable to secure confirmation on this supposed practice.

Tracking Down the Source of Trouble.

The problem in the field increased in seriousness, and in 1937, in view of the fact that we did not appear to be making much headway in securing actual facts as to what rusting difficulties were being experienced by others, the author's company embarked on a program of incorporating oiling systems which were designed to lessen chances of contamination, water leaks, etc. It was believed that we would thus be in a better position to face the problem and make sure that everything we did in our shops would offset any sources

of rusting. Meanwhile, laboratory investigations were under way. Then in April, 1938, corrosion was encountered in a 1200-lb. 925° F. topping turbine, using a modern highly refined oil. Rusting occurred within a period of a few hours and to such an extent that it became necessary to shut down and clean or replace certain steel governor parts; in fact, even some rust-resisting steel parts showed signs of attack.

Samples of the oil were examined. Very little change from the original characteristics were noted other than a cloudiness due to moisture (we found 0.02 per cent moisture).

The samples were divided into two parts, the second being freed from moisture and contamination by heating and centrifuging. Polished steel specimens were then immersed in the original and cleaned samples. In the original the steel rusted severely within 24 hours, while that immersed in the cleaned oil showed absolutely no indications of rust or corrosion. The corrosion products on the rusted specimen were identified as black oxide of iron. Now it appeared we were approaching an answer to the trouble, as the cause of the rusting was obvious.

Developing a Rusting Test for Oils.

Meanwhile, we had been investigating some of the solvent-refined oils, using a rusting test which we had devised. This test, an outline of which follows, is the forerunner of the present A.S.T.M. Test D 665-44T, the basic principles still being used. A 350-ml. sample of oil was placed in a tall-form beaker and set up on a stirring device accommodating six samples. Stirring was started and a flat polished steel specimen was then suspended in the oil. After 10 minutes stirring, 1 per cent of distilled water was added and stirring continued daily for 8 hours at room temperature with an overnight shutdown period, for a total time of 5 days. Specimens were then removed and observed.

Evidence indicated that solvent-refined and highly refined oils appeared to be those allowing rust to form when water was present. It was as if something had been removed from these oils, perhaps natural wetting or inhibiting constituents. If so, we reasoned, from what had been stated by some refiners using solvent refining, these constituents would probably still be present in conventionally refined oils of the Pennsylvania, Mid-Continent, and Coastal types and naturally then, such oils would not allow rusting.

This reasoning was disproved early in our investigations covering tests numbering over 100 on various oils and combinations thereof, and including practically all of the turbine oils then on the market. Thus, early in 1939, we reached the conclusion that many highly refined oils, irrespective of their base or method of refining, were conducive to rusting and corrosion in the presence of water. With this evidence we started to contact the refiners and present our "story."

Results of Tests.

As an example of results obtained, a few typical results are given in Table 1. It does not take much change in an oil to either "make or break" it, in so

TABLE 1. Results of Rusting Tests with Various Oils.

Oil No.	A.P.I. Gravity	Refining Method	Remarks
1	32.0	Highly refined	Rusted badly
2	33.0	Lightly solvent	Rusted
3	28.4	Conventional	Rusted badly
4	32.0	Conventional	Rusted badly[a]
5	22.5	Conventional[b]	Rusted badly
6	30.0	Solvent	Rusted badly
7	21.5	Conventional	No rust
8	27.0	Vacuum still	Rusted badly[c]

[a] Stated to be a 100 per cent Pennsylvania oil.
[b] A coastal oil.
[c] A Mid-Continent oil.

far as its rusting characteristics are concerned. As an example, the maker of oil No. 4 refines in two plants from the same crude and to the same finishing specifications. They desired to see what the oil from "their other refinery would do." It did not rust, yet it was essentially the same oil. Additional checks confirmed the results.

Again oil No. 7, which showed no rust, made from a single crude in a single refinery on an additional sample purchased some time later showed very bad rusting tendencies.

In the case of oil No. 5, to illustrate the effect of the degree of refinement on rusting, the supplier of this oil furnished samples of their "run" in two lower stages of refinement. That in the lowest stage allowed no rust and the one midway between the lower and finished stock showed slight rusting.

A comparison (Table 2) of the inspection characteristics of several oils which allowed and did not allow rust may be of interest. In general, color, neutralization, and demulsibility indicative of the degree of refinement in a given type oil.

TABLE 2.—COMPARISON OF INSPECTION CHARACTERISTICS OF VARIOUS OILS.

	Rusting Oils		Nonrusting	
A.P.I. gravity	28.4	22.5	28.6	21.5
Color	1	1½	4½	2½
Viscosity	150	155	220	157
Viscosity index	62	0	90	0
Neutralization number	0.02	0.01	0.08	0.10
S.E. number	30	45	60	100
Demulsibility	1620	1620	1300	1300 at 180
Carbon residue	0.03	0.02	0.19	0.02

During our investigations, it was determined that even the newer-type stable oils build up immunity to rusting as they age through use. However, sometimes they required as much as 12,000 to 15,000 service-hours before they would pass a rusting test.

Also, in our investigation we determined that rusting could be eliminated through the addition of used oil or by the addition of a nonrusting oil, by the addition of small amounts of fatty acids. Even the addition of a mineral cutting oil or some soluble oil (such as those mixed with water for cutting purposes) would eliminate rusting. Commercial polar compounds imparted inhibitive properties. However, in all these cases of additions, the other desirable characteristics of the oils were reduced to a considerable extent.

The author's company believed they had succeeded in showing what conditions existed and continued to press the refiners for a solution to the problem. We are not refiners but had presented the foundation for their subsequent investigations.

RUSTING "SHOWS UP" IN NAVY TESTS.

We would like to point out one further incident in this rusting problem, one having to do with marine apparatus, showing that rusting was not confined to lighter oils, and which we believe was most instrumental in securing the Navy's interest in the problem. The company had always used a 425-sec. second-grade turbine test oil for shop testing on marine reduction gears. Early in 1938, in testing marine apparatus, we were obliged to use Navy approved (Navy symbol 2190) oil. This oil has a viscosity of 185–205 sec. at 130 F. On a special so-called "full-power" test, severe rusting was encountered during preliminary runs. The oil used was that currently being used by the Navy. A competitive approved oil was tried with no improvement and finally a second competitive oil, again with no improvement, in fact the last used oil rusted so badly that it is believed an outline of the conditions encountered will be of interest.

The last oil was chosen because of the fact that the refiner, whose aid had been solicited, had stated their "oil has not rusted on other gear installations."

and who, in addition, offered the services of their marine engineer to aid in solving our difficulties. This engineer with the author concluded the test, the schedule for which follows:

Sept. 12. New oil in system.

Oct. 4. A black gritty deposit noted on back faces of gears. Not mill scale, as all parts had been pickled. Perhaps the rust was due to acid in the oil. Oil washed with neutral distilled water; however, no chlorides or sulphates detected and a pH of 6.8 found.

Oct. 5. Sample of oil removed from system. Water content 0.50 but no acidity; pH 6.85. Finely divided black iron oxide present in the sample. Was this contamination due to an improperly cleaned system? Oil removed, centrifuged, and replaced. Water removed by centrifuge showed pH of 6.75.

Oct. 7 to 10. Unit running and an apparent over-all improvement.

Oct. 12. Rusting again increasing. By-pass centrifuging.

Oct. 18. Conditions so bad unit had to be dismantled. Black-iron-oxide deposits over everything. Thrust-bearing shoe blocks severely attacked. Deposit identical to that found in the oil October 5, and in every way similar to deposits resulting from laboratory tests.

"PROVING" THE PROBLEM TO THE REFINER.

The refiner's representative, who witnessed all operations, agreed that the conditions existing very definitely indicated that rusting had immediately proceeded during the period from September 12 to October 4. It was then decided to clean up the entire system, flush with used turbine test oil which had passed a rusting test, with the hope of providing an inhibitive coating on the parts. Then it was planned to rerun with a new charge of the same type of Navy oil. We had meanwhile examined eleven of the then available approved Navy oils and found that all except one failed to pass the rusting test. The one which did pass, unfortunately, was not immediately available. In view of the emergency, it was deemed unwise to take any further chances. Thus, in order to complete this important test program, with Navy permission, we procured an oil made specially for us from stock which had passed a rusting test, and carried the test to a successful conclusion. This oil was not Navy approved; it simply had the required viscosity characteristics, but probably would not have passed the Navy work-factor test.

Later, a supply of the Navy approved oil passing the rusting test was procured and used on all subsequent tests with no further rusting difficulties. This is an inhibited oil and is still being used. No further difficulties have been experienced to this date.

In shop tests where a light 150-sec. oil is used, no rusting has been experienced with, we believe, two exceptions. This is due to the fact that such tests are generally run on "used" oil which does not allow rusting. Laboratory tests, however, have indicated that these oils in their new state are borderline, sometimes passing and at other times not passing the rusting test. Steps were taken some time ago to have our suppliers add an inhibitor to forestall any rusting should a new batch of oil be used. New oil probably caused the rusting previously mentioned. The same conditions apply to our heavier test oil (425 sec.).

As a result of this procedure, we have for the past 6 years been entirely free from rusting difficulties in our shops from these two sources.

Later, rusting was experienced in our machine tools where highly refined oils were used and, as a result, we insisted that all such oils should be inhibited. Further troubles were eliminated, and all oils used for this purpose must now pass a rusting test.

The author's company at that time issued an instruction bulletin on turbines, one section of which dealt with lubrication. With our investigations pointing to the cause of rusting in the field, certain stop-gap recommendations were issued. These included the addition of an old oil to the new oil, and also suggested that in the case of a new turbine installation, old oil from an existing turbine should be used in the new unit and that the new oil be placed in the old turbine unit. Several refiners approved of these temporary recommenda-

tions. While these suggestions were known to prevent rusting in the field, it was also realized the practices would tend to deteriorate the new oil quite rapidly, but in the emergency it appeared to be the most feasible solution. These recommendations were withdrawn as soon as it was demonstrated that satisfactory oils would be available from the refiners.

Work of A.S.T.M. Committee on Turbine Oils.

We would now like to call attention to an A.S.T.M. committee, Technical Committee C of D-2, which was organized in 1940. A Subcommittee XI on Turbine Oils had functioned for some years, but was discontinued in 1938, when "there did not appear to be any additional work that should be undertaken by the subcommittee." In January, 1939, the author's company recommended to the American Society for Testing Materials that a new Subcommittee on Turbine Oils be established, and in June of that year an agreement was reached to form such a subcommittee, with the result that Technical Committee C was formally organized in January, 1940.

Two sections were instituted, Section I on Turbine Oiling Systems and Section II on Rusting Tests; the latter with the author as chairman, and refiner, user, and builder representative membership. The U. S. Navy Engineering Experimental Station is also represented.

At the March, 1940, meeting, a review of available methods of rust-testing was undertaken, and arrangements were made for the co-operative testing of six oil samples. The review indicated only two or three methods of test. In June, 1940, the first test results were submitted. Every co-operating laboratory reported; all were in substantial agreement, and all submitted photographs of their test specimens. Figure 2 illustrates results of the author's company.

At this meeting, it was agreed to conduct future tests at elevated temperatures in order to simulate turbine-oil temperatures. During the next year, additional co-operative test work was carried on, and in October, 1940, the results appeared to indicate that the test developed by the author's company had the most possibilities. All through the activities of the section, most substantial agreement ensued and in June, 1941, it was decided to publish the so-called Westinghouse test for informative purposes, the modifications to include running at 140 F. for 48 hours, instead of the five 8-hour periods at room temperature, and with 10 per cent water added instead of 1 per cent.

Standard Tests Developed.

In January, 1942, additional co-operative tests resulted in such close agreement that it was voted to recommend the presentation of the method to the society as a tentative standard. As an example of this close agreement on the part of the co-operators, a list of results is shown in Table 3. The descriptions under each oil are the co-operator's ratings.

Table 3.—Results of Rusting Tests on Turbine Oils by Various Laboratories.

	Light Oils, Nos.			Heavy Oils, Nos.		
Laboratory	13	14	15	16	17	18
A	Severe	Very light	None	Severe	Few spots	None
B	Severe	Few spots	None	Heavy	Few spots	None
C	Severe	Traces	None	Heavy	Traces	None
D	Severe	Few spots	None	Heavy	Traces	None
E	Severe	Few spots	None	Severe	Slight	None
F	Severe	Light	None	Heavy	Light	None
G	Severe	Few spots	None	Heavy	Traces	None
H	Severe	Very light	None	Severe	Slight	None
I	Severe	Slight	None	Severe	Light	None
J	Severe	Slight	None	Severe	Slight	None
K	Severe	Slight	None	Severe	Light	None
L				Severe	Light	None
M				Severe	Light	None
N	Severe	Slight	None	Severe	Light	None

Oils

13 A new oil with which marked corrosion was experienced.
14 A borderline oil, permitting very little corrosion.
15 Definitely inhibits corrosion even in concentration of 10 per cent by volume in new corrosive oil.
16 2190 Navy type oil. Severe rusting experienced in service.
17 2190 Navy type oil. Occasional rusting experienced.
18 2190 Navy type oil. No rusting experienced in three years.

In June, 1942, the method was adopted as a tentative standard (D 665-42 T), and plans were made to continue co-operative tests and to investigate the possible use of sound specimens. The committee had been organized exactly 2 years, and its membership was congratulated by the secretary of D-2 on the progress made. It was further stated that the "discovery" of the rusting problem together with the preparation of a rusting test was an important contribution to the petroleum industry.

In June, 1943, with an additional year of co-operative effort with round specimens, a further revision of the method was contemplated. This was to include the use of round specimens and some minor changes in procedure, yet basically the original test was retained. Again, as an indication of the close agreement between the several laboratories, Table 4 gives some results obtained on round specimens. Results of tests by the author's company are shown in Figure 3.

TABLE 4.—RESULTS OF RUSTING TESTS ON TURBINE OILS USING ROUND SPECIMENS.

	Heavy Oils, Nos.		
Laboratory	16	17	18
A	General	Traces	None
B	Heavy	Traces	None
D	Heavy	Traces	None
E	Severe	Slight	None
F	Heavy	Light	None
H	Severe	Light	None
J	Heavy	Slight	None
K	Severe	Light	None
L	Severe	Moderate	None

Oils

16 2190 Navy type oil. Severe rusting experienced in service.
17 2190 Navy type oil. Occasional rusting experienced.
18 2190 Navy type oil. No rusting experienced in 3 years.

METHOD REVISED FOR FINAL APPROVAL.

In June, 1944, the method was revised (D 665-44T) to provide for the use of a ½-inch round specimen. The method involves stirring a mixture of 300 ml. of the oil under test with 30 ml. of distilled water at approximately 1000 Rpm. and at a temperature of 140 F., with a round steel specimen immersed therein. After 48 hours contact with the oil-water mixture, the specimen is examined to determine whether or not it has rusted.

No doubt the method will be recommended for advance to standard in 1947. Meanwhile a possible reduction in testing time from 48 hours to 24 hours is to be investigated. Increased testing temperatures are also to be investigated. The section will also undertake setting up a test with synthetic sea water to be used in testing oils for use aboard ships.

This is the first time the author's company has publicly presented data on this most important question of rusting, although it required considerable restraint not to do so, especially in the early years, for the problem of eliminating rust was very serious and the results of the investigation most unusual and far reaching.

ACKNOWLEDGMENT.

We desire to acknowledge the helpful suggestions of Mr. M. D. Baker, Chief Chemist, West Penn Power Company, during the early stages of the investigations. To the A.S.T.M. members, for their unstinting co-operation and understanding in making the work of the section a success, we express our thanks. Finally we thank our refiner friends who so kindly listened to our stories and who when they "saw the light" did something about it. Immediately taking hold of the problem, they in a very short while produced results. Present-day turbine oils are not only rust-resistant but definitely improved, in particular with respect to resistance to oxidation.

ENGINEERING LESSONS AND GAINS OF THE RECENT YEARS.*

"The recent period of engineering activity under altered objectives has given engineers a vast fund of detailed know-how that will be valuable in unsuspected ways for years to come for improvement of the old and development of the new."

On one of those grim days in August, 1942, a landing vessel drew up on the sands at Guadalcanal and men began pitching packages overboard to be towed ashore. Among them were portable marine radio receivers in sealed-metal cases, which, upon being fished out of the surf, could be quickly set up to provide vital communication for the landing operations. The metal cases of three of these radio sets were punctured by Zero strafing, so they promptly sank. But they were not given up for lost. Because every bit of radio equipment was desperately needed, the marines retrieved the three sunken cases. After the salt water was emptied out, the radios were laid in the bottom of a fresh-water creek for several hours for further washing, following which they were placed over a slow fire under a tent and dried. The three sets were placed in operation and worked satisfactorily.

The proximity fuze, one of the most successful of our ordnance developments, by which the shell would explode when in the neighborhood of its target, contained thimble-size radio tubes that had to function even under accelerations of 10,000 times gravity. The fuze contained a wind-driven turbine generator the size of a man's fist that, almost independent of shell velocity, turned at a constant speed of 40,000 Rpm.

To bring the control gyroscope of the electric torpedo up to speed required a super-special motor. It could never run longer than one-fifth of a second, in which brief time it had to accelerate the gyro inertia wheel from standstill to 12,000 Rpm. The motor weighed less than nine pounds but developed 22 peak horsepower. To achieve this the materials were worked to the utmost. Current densities in the armature copper amounted to 63,500 amperes per square inch and nearly that in the field winding. The motor would have melted in a second or two of operation.

These episodes are but three of thousands of like kind. They are interesting in their own right, but more important they indicate the kind of thing engineers were called upon to perform. The general fact is that until about 1941 the considerations that guided a product-engineer's hand were life, reliability, performance, and cost—especially cost. At the onset of conflict these were replaced by a new combination of objectives: maximum rate of production; ability to operate at high altitudes, in extreme cold, in great heat, and high humidity; to withstand shock and corrosion; to operate at phenomenal speeds or outputs or both; be both small and light weight; and be transportable with rough handling literally to the ends of the earth. Life became a matter of weeks, hours, or even fractions of a second. Cost came at the bottom of the list.

SPECIFIC LESSONS.

Engineers have returned to a normal regime in which the ruling factors are again cost, reliability, performance, and life. One would expect them to,

*Reprinted from the "Westinghouse Engineer" of January 1943.

bring along a body of new information, bought at high price and under tremendous pressure, but a portion of it useful in the engineering ahead. They have indeed. It is much too early to measure the true value of these lessons; this knowledge will show up in apparatus for many years to come. However, a variety of case examples show the nature of the useful technical information. Take corrosion for example.

Protection for "Tin Fish."—Electric torpedoes became the business of transformer engineers. Not the least of their problems was how to protect the thin steel shell of the torpedo body (conventional torpedoes have thick walls) from the corrosive action of sulphuric acid on the inside and salt water on the outside. "Insulation" against these vigorous corrosion agents came, surprisingly enough, from a highly specialized electrical insulation.

The materials engineer in charge, a man with chemical training and electrical-research experience, contemplated the highly resistive qualities required for both acid and salt water. To his surprise he found they coincided well with those of high-grade electrical varnish (Thermoset). The steel torpedo shell was Parkerized, given but a single dip in varnish of the same sort used in transformers, and baked. The result was a treatment that gave, in one operation, corrosion protection to both the inside and outside—and at low cost and slight expenditure of labor and time. Furthermore, the baked synthetic-varnish surface was remarkably abrasion-resistant, a desirable attribute, considering the rough handling to which a torpedo is subjected. The ultra-protection of the "armor" coat was indicated when a torpedo was fished out of the sea after nine months' immersion and found to be in perfect condition.

Protection for Black-Oxide Treated Parts.—Corrosion protection for splines and gears sometimes presents a special problem in that whatever is done to the surfaces must not change the overall dimensions. Hence plating is taboo because it adds to the thickness and would wear off because it is relatively soft. A designer of electrical apparatus for aircraft was posed with the problem of how to remove oxidizing salts from small recesses of steel parts subjected to black-oxide treatment. A bath in chromic acid was tried. This worked well enough, but more important, it was discovered that the oxidized parts thus washed withstood the standard salt-spray test several times longer than before. This was not too surprising as chromates are well-known corrosion inhibitors. The chromate, however, is not permanent, as continued exposure to water removes it. It seemed that if some protection could be given the chromated surface perhaps it would be more permanent. The chromate-washed nitrided parts were then treated with one of the well-known corrosion inhibiting oils that have the ability to displace moisture from a surface. The parts were thereupon able to undergo the salt spray 200 hours instead of two hours for plain oxidized parts. A test at 100 per cent humidity was stopped after 50 days, as it appeared it could go on indefinitely without appearance of corrosion on the triple-treated surfaces.

Cathodic Protection for Water Tanks.—The life of the usual galvanized-steel electric water-heater tank is greatly influenced by the character of the local water. Some 20 years' service can ordinarily be expected from a properly galvanized steel tank, which is by all odds the most economical tank construction now available. In a few areas—curiously enough these are the areas in which the water is soft rather than hard—galvanized tanks corrode in a small fraction of 20 years. Sometimes a water tank in a house on one side of the street lasts indefinitely, whereas across the street, served by a different water system, a tank fails in two or three years. The difference seems to lie in the lack of lime or carbonates in the water, which partially protects the tank wall. Corrosion is largely the result of electrolysis.

Inasmuch as corrosion cannot be eliminated, at least the attack can be diverted to something less objectionable than the zinc surface. Favorable results have been obtained experimentally by the fairly simple expedient of suspending inside the tank a magnesium-alloy electrode electrically grounded to the tank. Galvanic currents are such that ions flow away from the magnesium electrode instead of the tank wall, thus destroying the magnesium

instead of the zinc. When the magnesium electrode is well disintegrated it can be readily replaced by a new one.

This manner of preserving the interior follows the well-known principle of cathodic protection, long applied to pipe lines, water tanks, and other buried structures that are subject to galvanic earth currents.

Corrosion Promotion.—Corrosion is not always undesirable. In one spectacular instance a means of creating and maintaining a surface film is essential. This is on the commutators of aircraft generators. When airplanes began operating significant periods of time at altitudes above 30,000 feet, the life of carbon-brushes diminished to a few hours. In the substratosphere the thin copper-oxide film normally present on the commutator surface at ground level is lost. This oxide film acts as a lubricant for the brush face. Without it the carbons ride on raw copper, and are quickly ground to dust at the high speeds at which aircraft generators turn. Also, the absence of the film decreases the brush-contact resistance, which has an adverse effect on the electrical characteristics of the generator. The high temperatures at which commutators operate nullify conventional methods of lubrication.

Armed with this information, research engineers developed a special treatment for brushes that creates on the commutator the necessary oxide film as rapidly as it is worn away. Essentially the treatment is an impregnation of the brushes with certain halide compounds, which work to the carbon surface as the brushes get hot. Brushes treated in this manner are proving superior for certain other non-aircraft applications where commutating conditions are severe.

Painting with Molten Metal.—Another big gun in the ever-present campaign against corrosion is the molten-metal spray. Frames and panels of radio-communication equipments have been protected in this manner, in which the steel was first shot-blasted and then "painted" with a film of molten zinc.

This method is being applied regularly to the protection of shunt capacitors for pole mounting where ordinary paints have seemed inadequate, because the handling during installation often scores the surface, paving the way for early corrosion. It is being applied also to transmission-line protector tubes and may be extended to other communication equipments, train-radio sets, and broadcasting equipments located in certain localities. Metal-spray protection will be useful for other apparatus that must be subjected to corrosive atmosphere such as salt air. It has been reported that the upper structure of the *Normandie*, for example, was protected in this manner.

Particular merit of the metal-spray idea is that the coat can be made as thick as desired, whereas, with galvanizing, the zinc is more limited in thickness. By molten-metal spraying, surfaces up to eight mils have been applied readily to capacitor surfaces. Even if the sprayed metal is scored all the way through to the base steel, corrosion is less likely to ensue because of the more favorable relationship of zinc and steel in the electromotive series—oxidation of steel being in part a galvanic phenomenon. Sprayed metal requires no time to dry whereas conventional baking methods require both furnace equipment and time. The coating is complete and has its final durability as soon as it is applied.

Protection from Shock.—Undoubtedly more has been learned in the last half dozen years about the effect of shock on apparatus than in any previous two decades. Mostly this is because so much equipment has been subjected to the effects of gun fire. The attention of engineers generally has been focused on the problem, which inevitably leads to a better-directed and more concentrated approach to the solution. For example, methods of making shock tests and specific shock-test equipments were developed, which permits comparison of shock-test results made in different plants.

Until the recent emergency period there was no standardized method of shock testing or machines for shock tests. At the Navy's request several types of shock machines were developed. The outstanding and largest of these were shock stands equipped with a 3000-pound hammer, which could be dropped six feet giving an 18,000 pounds-feet blow. Five of these of identical design were built and have been used extensively in the plants of three

electrical manufacturers and in two of the Navy's laboratories. Among the special shock machines was one developed for the testing of switchboard-type instruments. These various machines make it possible to test a variety of machines and have the results correlated throughout the industry.

Equipment built to resist shock is generally more expensive than equipment that has to endure only normal service, hence it is not logical to expect that all apparatus will be so constructed. However, some improvement of regular apparatus will result even though the extreme methods of shock proofing may not be applied. For example, engineers learned that the heaviest and most rugged switching devices don't necessarily stand up against shock resistance as well as lighter equipment that can be better balanced. This knowledge will have an effect on non-military switchgear equipments, particularly the smaller devices.

In the construction of radio equipment for use on shipboard, it was found that mountings made of cast aluminum were quite superior because of their high damping characteristics. Electronic devices generally will be improved because of the need for protecting them against shock. It is now possible to protect large tubes and to isolate contactors that cause vibration, using isolators of various types such as springs and damping pads. This knowledge will be specifically of benefit in building radio equipment for Stratovision. Also, some of this knowledge has been applied to the improvement of medical X-ray tables.

The method of sealing metal to glass, using metals of the Kovar type that have virtually the same coefficient of heat expansion as glass, provides as well as an excellent seal substantial improvement in the ruggedness of tubes. As compared with the feathered-edge types of metal-to-glass seals that had long been used by the industry, Kovar can be applied in thicker sections, resulting in an attachment much more rigid and shock resistant. This sealing method is being extended generally to the manufacture of electronic tubes for F-M and A-M broadcasting, train radio, Stratovision, and radar, as well as the vacuum tubes for the frequencies used in induction and dielectric heating.

Shock Lessons from Miniature Lamps.—Miniature lamps of the 6-, 12-, and 28-volt variety were used literally by tens of thousands mostly on vehicles such as tanks, jeeps, and airplanes. Characteristic of all this service was extreme vibration and shock, which is the worst enemy of lamps with their precision and intrinsically fragile parts. As one might expect during the early part of the war the record of lamps applied to tank service was discouraging. Here the life was measurable not in hours but in miles, frequently fifty miles being the absolute maximum life. As experience accumulated, general improvement in shock and vibration resistance was achieved with miniature lamps which will be of benefit to this type of lamp generally.

Perhaps even more important, however, was the focussing of attention by manufacturers of all lamps in general on the problem. With this need for an aggressive attack on the problem came a better understanding and coordination of shock testing and the effect of rough service of small lamps. Out of this will inevitably come an improved construction for all types of vehicle lamps such as those used on aircraft, Diesel trucks, and railroad passenger cars.

Newer, Better Lighting.—Numerous lamps developed for special purposes in these recent rugged years will have almost direct carry-over. One of the most spectacular of miniature lamps—that for aiding pilots downed at sea and shipwrecked seamen—will have an appeal to every motorist. This so-called sea-rescue lamp, developed for operation from a hand-turned generator, provided a long-range beam to attract searching parties. The lamp is a small walnut-size bulb with an internal silvered reflector and a precision-located filament. This combination provides a strong, sharp beam of nearly 1200 candlepower.

The lamp will have various more ordinary uses, possibly becoming the basis for an automobile emergency or trouble light located on the end of an extension cord that plugs into the cigarette-lighter outlet on the instrument panel. The convenient lamp can be used for under-the-hood operations, to provide light for changing a spare tire, or reading a road sign or house number,

or for giving an emergency signal in case of an accident along the road at night. The lamp utilizes its seven watts of energy so efficiently that with it a road marker 100 feet away can easily be read under normal conditions.

Another type of miniature lamp utilizing the glow principle carries over to a lamp for use in domestic electric refrigerators for the control of bacteria and mold spores. This lamp, slightly smaller than a golf ball, irradiates the air in the refrigerator as it circulates past the lamp, giving a reduction in bacteria and mold spores, and a consequent reduction in food spoilage. In addition, the ozone produced in the cabinet's air destroys odor-bearing vapors.

Construction of the refrigerator Sterilamp as a miniature of the conventional Sterilamp was not practicable with reasonable efficiency. Engineers, casting about for a suitable bactericidal lamp for refrigerator service, took note of the glow type of lamp originally developed for fliers and sailors forced into life rafts during the war. By altering the glass and making minor modifications in the electrodes, an extremely efficient refrigerator Sterilamp has resulted.

Mercury-vapor lamps are being built in new forms and larger sizes to provide a better answer to the problem of lighting industrial areas, particularly those with high ceilings. Most recent of this growing family of high-efficiency lamps is the 1000-watt high-pressure, air-cooled unit, which, although about the size and shape of a fountain pen, provides a concentrated, high-power source for factories, particularly those with high ceilings. This lamp will continue to serve its original purpose, but in addition it appears to have application in photochemical processes where the reactions are expedited or controlled by ultraviolet and visible-light radiation.

General Changes in Engineering.

Whether the "good old days" were really good or just seem so at a distance is always an open question. In either case, to crave their return is only wishful thinking. This is fully as true in engineering as in any other field. Although engineering has resumed its more normal activities, it is by no means the same as before the interruption. The last few years have left permanent marks on the profession, mostly good, some not so good—but anyway, marks. There are many such marks, most of them vague and intangible. Frequently, one feels strongly that this is so without being able to cite specific evidence.

In numerous plants engineers became much better acquainted with factory men and methods. And vice versa. With production paramount, the usual model-shop, pilot-plant steps, by which difficulties of large-scale manufacture are avoided, had to be side-tracked or telescoped. Every difficulty with a new design—or for that matter, with an old one—with a material substitution, or from any one of a score of other sources, required instant attention by the design engineers involved. This urgent production necessity resulted in many more personal contacts between design and production departments instead of the usual indirect routines. Frequently design-factory liaison engineers were placed in the shop itself. The outcome has been a better understanding by technical men of shop problems, methods, and men. Likewise production people have an appreciation for the initial creative phases of products and machines. This interchange has large but intangible benefit in the aggregate.

Being Critical of the Accepted.—The great pressure for unheard of production rates had another incidental good. It forced examination of many time-honored ideas and methods, sometimes with astonishing results. It not only resulted in specific benefits but also taught the general lesson of the value of frequent critical examination of the conventional.

The Westinghouse electronic tube plant soon found itself with the problem of manufacturing several times more large tubes than it had ever before provided. Furthermore, the physical arrangement of the plant was such that further expansion of facilities was not possible. Somehow the greatly stepped up production would have to come from the existing space. This led the design and production engineers to re-examine every step in tube manufacture for ways of increasing output. The traditional method of sealing glass to metal

was in horizontal lathes. This resulted from the fact that the men who performed these sealing operations had been machinists before the skyrocket rise of electronics. They brought with them, naturally, their previous experience which was with horizontal lathes. One harassed production engineer, however, considered that time and space might be saved by using vertical machines. For trial some old drill presses were found and the chucks rearranged so that the glass portion of the tubes were held in the upper member and rotated around a vertical axis during the fastening operation to the metal member held on the fixed bed below.

The results were astonishing. The vertical machines occupied only a fraction of the space of the horizontal ones. Furthermore, gravity now worked in favor of the joining operation instead of, as in the horizontal machines, attempting to distort the seal. These and other advantages brought about an eight-fold improvement in electronic-tube production from the given working area. The idea has been so beneficial that it has been generally adopted for manufacture of all types of large tubes such as those for X-rays, radar high-frequency heating, F-M and A-M broadcasting.

Such experiences have taught engineers in many plants that there is nothing sacred about ways of doing things just because they have been long accepted. This is indeed a wholesome attitude and for a time will have many engineering and product benefits.

Design and production engineers find themselves equipped with machines and test setups that normally would not have been available. These result from the need for such vast quantities of products that literally demanded machines, tools, and setups. In the normal course of events many of these machines couldn't be justified but now that plants have them they will be put to good account. The result is more accurate devices produced at less total cost.

The greater diffusion of technical knowledge that comes as a by-product of conditions of recent years acts as an accelerator for many lines of development. The freer interchange of knowledge, the necessity for standardization of mountings, physical dimensions, etc., the more frequent contacts of technicians and with other plants are positive gains. As a single example, the importance of vibration and machine design is now much more extensively appreciated, as is indicated by the fact that electronic machines for producing continuous vibration for test are now being sold in numbers. Ten years ago vibration-test programs were rare.

Greater Responsibility for Engineers.—Design engineers in many plants find themselves with more responsibilities than when they last produced the normal kind of things. In general, drawings are much more elaborate, much more detailed and more numerous. There are many reasons for this. Apparatus, particularly in the electronic and control field, is becoming much more complex. Also, during the years of large quantity ordnance production many people with limited shop experience had been brought into production organizations. Also, the greater use of incentive systems, and greater segregation of time rates require that less freedom of discretion be given the production worker. Processes, dimensions, treatments, and assembly methods must be specified in more detail. All this can hardly be counted on the plus side of the engineering ledger but is a fact to be reckoned with in many lines of technical endeavor.

Also, hardly to be counted an advantage is the fact that engineers had a tendency when the emphasis was on production to lose their cost consciousness. This is particularly true because many young engineers have come into organizations who have had little or no experience with the normal ways of doing things where expense is a major consideration. This return to a keen awareness of cost considerations in design is made the more difficult because of the natural and commendable trait of engineers to like to do the best possible job, which frequently of course is not always compatible with practical considerations of economy.

Material Scarcity Spurs Ingenuity

The shortage of materials that plagued engineers throughout the war took a curious turn at the end of hostilities. Some materials that had been scarce became plentiful and others that had been reasonably plentiful became difficult to get. For a long time aluminum was among the most scarce of war-needed materials but with the sudden decline in aircraft manufacture aluminum became relatively plentiful, and its place on the shortage list in certain types and shapes was occupied by steel.

Problems of Steel.—During the middle and latter part of 1946, engineers found it increasingly necessary to reduce their usage of steel, in order to keep the production line in action. Engineers have displayed the same ingenuity evidenced during the emergency in these matters of substitution. A study of the electric range disclosed that it would be possible to make 27 substitutions of aluminum for steel, eliminating a total of 38 pounds of steel per unit. Aluminum can be substituted in many places where strength is not a consideration, such as for baffles, traps, and other non-load-bearing parts. No change resulted in any compromise with quality and some were definitely advantageous.

The cover or exposed upper part of electric irons is now made from aluminum, with definite advantage. The new aluminum surface requires less finishing time and a few ounces are cut from the iron's weight. There is no chrome surface subject to injury, and rejects are reduced.

Even cast iron has at times become strangely short. In one product requiring about 65 pounds of mass for a balancing function the customary cast iron could no longer be readily obtained. As a substitute, thick sections of a boiler plate were bolted together. This change proved to be not only an actual economy but also was easier for workmen to handle.

Because steel rivets became difficult to obtain, aluminum rivets have been substituted in some cases where shock is not encountered. In certain lighting fixtures aircraft-type aluminum rivets have been used for screws.

Control wires with coverings of different colors simplify assembly, but lately it has not always been possible to secure wire in a desired color. Thereupon, it became necessary to devise a means for coloring the available wire inasmuch as the white cotton-covered wire is more readily available. On short wires this was done by using a wrapping of colored scotch tape, or by a short piece of colored insulating tubing over the cotton. On longer wires, and where space factor was a problem, the wires were racked and sprayed with colored lacquer.

When the supply of sapphire jewels from Switzerland became strangled in 1941, engineers turned again as they had 25 years ago to other types of bearings for instruments, which not only were absolutely indispensable but were demanded in may times larger quantities than ever before. On this occasion, experiments with glass jewels have proved more successful, so much so that they will unquestionably live for certain applications. Glass is not as hard as sapphire, and, therefore, wear and friction of a steel pivot and glass cup are less than with the steel pivot and sapphire. Up to a certain point of stress, the glass is superior, but beyond that the sapphire is still preferred. Glass will continue to be used in some applications where the bearing loads are lighter.

Better Grids for Tubes.—A permanent improvement in electronic tubes comes about because tantalum became scarce. This forced electronic engineers to seek an alternate material for use as the grid wires on high-powered tubes. This was a particularly stubborn problem inasmuch as tubes were being built for larger and larger capacities and grids were being exposed to greater concentration of cathode power. It was recognized that platinum would be ideal in some respects, inasmuch as it has a high work function (i.e., it does not tend to give off electrons even when hot). However, platinum softens and weakens mechanically when high temperatures are reached. The problem was solved by making grids out of molybdenum wire coated with platinum. The moly retains its strength at high temperatures and serves to

support the platinum. This combination has another advantage, as platinum has the fortunate property of absorbing the thorium given off by the cathodes during operation. Without this property, thorium would accumulate on the surfaces and greatly lessen the tubes' capacity to function properly. This construction, which began as a substitute measure, has proved successful and will be extended to commercial tubes such as tetrodes for F-M broadcasting.

Bushings without Shellac.—Shortage of shellac has resulted in a major improvement in condenser bushings. The new construction requires only a small amount of shellac and therefore permitted uninterrupted production of badly needed high-voltage bushings and at the same time released large quantities of shellac for other uses. The new bushing is superior electrically and has entirely replaced the previous construction in the high-voltage class.

The new condenser bushing consists, as before, of layers of high-grade paper, wound under tension on the copper conductor, which is a copper tube or stud. In accordance with well-known condenser-bushing principles, sheets of metal foil are inserted at intervals. Except for an adhesive to bind the first turn of paper to the conductor, the paper is wound dry, with no binder between layers, as in modern transformer practice. There is, likewise, no subsequent varnish treatment of the insulator surface to interfere with oil penetration. After the winding had been made in this manner—usual except for the absence of the shellac between layers and the fina lvarnishing—and is machined to proper dimensions, the structure is placed in its porcelain housing. In the new bushing, the condenser is completely enclosed by upper and lower porcelains connected at midsection by a steel sleeve. Thus the condenser projecting down into the tank is encased in porcelain as is the upper end.

In this bushing the mechanical and electrical functions have been entirely separated. The condenser no longer assumes any of the mechanical load. All stresses are carried by the porcelain in compression. Completed bushings of this design have been subjected to severe shock and vibration tests with results that proved the porcelain and steel structure to be entirely adequate.

ASSOCIATION NOTES.

Banquet, 1947.

The annual banquet of the Society was held at the Statler Hotel in Washington, Friday, April 18, 1947. The occasion was outstanding in every particular, and was thoroughly enjoyed by all in attendance.

The pre-arranged speeches were: "Surface Ships in the Pacific" by Captain A. A. Burke, U. S. N. and "Engineering Horizons" by Dr. Charles F. Kettering, Vice President of General Motors Corporation. In addition, Hon. James Forrestal, Secretary of the Navy, gave an extemporaneous talk. All these were intensely interesting and were enthusiastically received. The two principal speeches are given in full herein.

"SURFACE ENGAGEMENTS IN THE PACIFIC."*

By Captain Arleigh A. Burke, U.S.N.

One of the biggest mistakes the Japanese made in this last war was that of underestimating American combat ability.

In the battle of Empress Augusta Bay, in the Solomons, four of our light cruisers supported by one squadron of destroyers, had the mission of preventing the Japanese from interfering with the landing of our Marines on Bougainville. The Japanese had a powerful force composed of heavy cruisers, light cruisers, and destroyers to do that interfering. One division of my Little Beavers in the van of our force made contact with the Jap powerhouse about one in the morning. We drove in at once—at high speed—until we could see the silhouettes of one Jap column. The orange flames on two of their sinking ships woke up the Japs—and all hell broke loose when our light cruisers opened up. The Japs fought back—and they fought back hard—but after several hours they retired in confusion—to their base in Rabaul—and they forgot about our Marines.

* One of the principal speeches at the Annual Banquet.

The Japanese high command could not understand why Admiral Amori had not defeated an inferior force—and they relieved Admiral Amori of his command. The Jap high command was not there—but Admiral Amori, and every Jap sailor in that battle, damned well knew why they had failed—they had run up against our "old Navy tradition".

The Navy has perhaps been criticized for adhering to its Naval traditions. The Navy does revere its traditions, for they were fashioned by the valor of our predecessors. We honor those gallant Naval heroes of American history who, by their fighting spirit and unselfish devotion to duty, helped in gaining and maintaining the independence of the United States. The most impressive sentence in any citation is, "His conduct was in keeping with the highest traditions of the United States Naval Service". Those traditions represent the principles of Americanism for which our ancestors fought. They represent the spirit of self-sacrifice, of willing cooperation and mutual support. They were built on combat ability, relentless determination, personal courage, leadership and guts.

As a combat organization we are proud of our Naval traditions. Our Naval traditions were born in the Revolution—when John Paul Jones preached independence with the eloquence of a man-of-war's guns. He demonstrated the effectiveness of carrying the war into the enemy's back yard. He started the tradition of bold, aggressive action. The gallant sailors in the famous actions of the War of 1812 gave following generations of American sailors the heritage of audacity and enthusiasm for battle. They brought out forcibly that well trained ships, well equipped and manned by bold crews with resolute leaders could obtain decisive victories against the greatest odds.

Each succeeding war has reemphasized the importance of the old traditions of personal courage, cheerful acceptance of great odds in battle and the will to win. Each war has added new traditions to the list.

In World War II, the Japs gained their new Pacific Empire quickly, and it was not until the United States wisely decided to attack that we stopped the hard-fighting Japanese on their route to unlimited conquest. There were many sea battles fought in the Fall of 1942—Savo Island, Cape Esperance, Santa Cruz, Guadal-

canal, Tassafaronga—all names that recall hard-pressed American ships stopping the Japanese onslaught. In the battle of Guadalcanal, for example, Admiral Callahan's force, composed of cruisers and destroyers, attacked four groups of enemy ships containing battleships at point-blank range near Lunga Point. One enemy ship was sunk immediately, others were set on fire, as more and more Japanese ships settled to the bottom of "Iron Bottom Bay",—but our cruiser *Atlanta* was hit by a torpedo. She lost power, and a Jap cruiser battered her unmercifully, killing Admiral Scott and many of her crew. In a few minutes, the *San Francisco* was engaged at close range by an enemy battleship and she took a terrific beating until the destroyers *Laffey* and *Cushing* made a short-range torpedo attack. They scored hits, but were themselves badly damaged—the *Laffey* sinking. At about this time the enemy battleship's fire smashed the *San Francisco's* bridge, killing Admiral Callahan, Captain Young and many other officers and men. However, the communications officer of the *San Francisco* was not killed—although he was seriously wounded. Young Bruce McCandless assumed command and displayed superb initiative, again bringing his ship into battle against what he knew to be an overwhelmingly powerful force. He boldly led our column of badly damaged ships against the enemy with the daring and steadfastness which he knew was expected of him by tradition—a tradition of personal initiative which Decatur established at Tripoli, with the same result—success.

This was also one of the many nights that Captain Wilkinson in the famous destroyer *O'Bannon*, wrote history. In this fierce battle the *O'Bannon* found herself surrounded by gun flashes and burning ships, both Americans and Japanese. Suddenly out of that hellish night a tremendous hull loomed up—topped by a Japanese pagoda mast. Wilkinson ordered—"Set torpedoes for a spread—fire when you are on". The *Hiyei* moved closer, to 1800 yards, when Wilkinson heard the swish, swish of torpedoes leaving the tubes, followed by the dull explosions which torpedoes make when they hit a well built ship below the waterline. The *Hiyei* stopped then, and she sank that same night—but the *O'Bannon* didn't get off easily. She soon found herself near a *Tenyru* class cruiser. More tin fish were launched. More dull explosions were heard, and the Japanese cruiser joined the *Hiyei*.

O'Bannon ended that night a wounded veteran. She did honor to the Marine Lieutenant whose name she bears—and she lived up to the traditions of the Naval Service which he helped make over a hundred years before.

Later Carlson's Marine raiders on New Georgia needed food and supplies. Their wounded had to be evacuated.

A small group of destroyers escorted into Kula Gulf four old World War I, four stack destroyers, which had been converted to high speed transports. Amidst both U. S. and Jap minefields, opposed by enemy shore batteries and in submarine infested waters—and despite a three-hour harrowing battle—they successfully accomplished their mission of support for the Marines.

These old 23-knot transports started out of Kula and averaged 26 knots back to Guadalcanal. That speaks well for the engineering plants in the old veterans and is a tribute to American engineering.

We studied the Jap "Tokyo Express" runs which they used to supply their large starving garrisons—and we decided to try General Sherman's tactic of the Civil War—that of keeping the enemy on the horns of a dilemma. Unfortunately, Admiral Halsey ordered me out of the "Slot" after four or five weeks up there—probably having heard something about unreported broken ribs. My successor, Captain Moosebrugger, on his very first night made contact with the Express. There resulted the battle of Vella Lavella, in which Captain Moosebrugger in a most spectacular, well-coordinated attack sank four enemy destroyers without damage to his own, using Sherman's well-tried tactics. He demonstrated to the Japanese both Sherman's strategy—the two-pronged attack—and Sherman's philosophy—"war is hell"!

In early November, Admiral Halsey made plans to capture a base on Bougainville. It was necessary to keep advancing so that the Japanese could not reinforce their large, harrassed garrisons. The few ships available had been operating continuously at high speed with few tender overhauls and little upkeep. This continuous high speed at times brought the most surprising consequences. At one time in the Solomon's campaign, Commodore Roger Simpson's squadron and mine were alternating on the attack line. The off-duty squadron returned to Hathorn to fuel. One day when we were pushed for time even more than usual, I decided to take a short cut through Blackett Strait. It might have

been mined, but we were in a hurry so we went through the Strait at a very high speed. While we were fueling I received a message from the beach to please call on the Commanding General of the Area, but as we had to get back to relieve Roger, I sent regrets with reasons, and shortly after proceeded again through Blackett Strait at high speed. When we relieved Roger's squadron I told him of the short cut and he also went through at high speed—received his invitation to call on the general—regretted—and returned at high speed. A couple of days later I again went through the Strait—and but fast.

This time I was invited to the General's Headquarters as soon as we stood into the Sound, and since we weren't in quite such a rush, I accepted and called on him. I was informed by my Army brother-in-arms that these damned destroyers had been knocking down the Army water's edge privies, and that he wanted it stopped.

Thereafter we sortied with more restraint. I didn't have a chance to warn Roger, and he came through the Strait again boiling—but that was nothing to the boiling of the General. Roger, I understand, tried to explain the advantages of periodic flushing, but apparently this was outweighed by the vigorous and embarrassing drenching of Army privates. Thereafter we both operated in the Strait in accordance with another old tradition—the "well considered risk".

Several months of high speed steaming followed, with no time for tender overhauls and no time for even cooling off the ships' engineering plants, this demonstrated again that American equipment, produced by manufacturers who were conscious of their mission, would perform far beyond specifications. Those ships were subjected to unusually high speeds and it was most fortunate for those of us at sea, that the home team was turning out gear which would stand the unusual strain of battle performance for a long period of time. I even owe my nickname to you, for if you had not produced this rugged equipment, Admiral Halsey would never have had cause to pull my leg about an average speed of "31 knots".

The battle of Cape St. George was fought a few weeks after the battle of Empress Augusta Bay. These few weeks were filled with bombardments, night raids, air attacks and the usual sleepless night. Everything was hurry, hurry, hurry. From the mo-

ment our torpedoes sank the first two ships, this battle was a running fight. The Japs did the running. It was a continuous battle for over three hours, and resulted in complete defeat of the Japanese force. The spirit prevailing that night was typified by the young Bluejackets who, overcome by powder fumes, were placed on deck by their shipmates, and, revived by the fresh air and sea spray, went back into the gun mounts again to continue the fight. As long as American youth hold that tradition, and as long as they have superior equipment with which to fight, the outcome of battles will be as certain as was the outcome of the battle of Cape St. George.

The story of the surface action of the six old World War I battleships in the battle of Surigao is well known to all of you. These old ships—manned by valiant sailors—prevented the Japs from reaching our transports—and from reaching home. It must have been humiliating—being sunk by the same old ships which they had "sunk" at Pearl Harbor.

That same night, another Japanese force came steaming through the Straits of San Bernardino. East of Samar were 16 of our small "jeep" carriers, screened by destroyers and destroyer escorts. This American carrier force, under Admiral Tom Sprague, sighted the strong enemy surface force at 6:45 in the morning—four battleships, seven cruisers and about nine destroyers. Soon the enemy was within range of the slow *CVE's*, and Admiral Sprague ordered his screen to drop back of the carriers and make smoke. The destroyer *Johnson* found herself smothered with enemy fire and was soon within 5-inch range of the enemy fleet. Commander Evans, Captain of the *Johnson*, attacked with torpedoes. One lone destroyer against a fleet, determined to fight, determined to protect the ships she was screening. Soon there was devastation on the *Johnson*—power was lost, and scores of officers and men were killed and injured; but *Johnson* kept firing. Two other destroyers, *Hoel* and *Heermann*, and a destroyer escort the *Samuel B. Roberts*, launched a torpedo attack. The *Johnson* had no torpedoes left and she was badly damaged, but she joined the attack anyway, as best she could, so as to draw fire from the enemy and to support her division mate with counterfire. These very small ships closed to within 2000 yards of the enemy and fired their torpedoes. Every man on those ships knew when they started their attack that there was no chance that such a small

force would come out of a battle against a fleet, but they went in with steadfastness, skill and enthusiasm, sacrificing themselves for the common good. Their powerful little attack was successful and the enemy turned, thereby giving our baby flattops more time in which to clear. But it was not enough, and the Japanese soon overtook the *Gambier Bay*, commanded by Captain Viewig. She was hit and disabled but continued to fight with her one 5-inch gun. The enemy bore down on the remaining American flotilla and Commander Kintberger in *Hoel*, and Commander Copeland in *Samuel B. Roberts*, and Commander Hathaway in *Heermann*, again made a desperate torpedo attack. They had no torpedoes now; they had all been fired, but the Japs did not know it, and the Japanese turned. They didn't like these little fellows who could fight so hard and who showed no fear. The *Johnson*, *Hoel* and *Roberts* were sunk along with *Gambier Bay*, but their courageous attacks, their dry runs on a feint which meant death, saved the rest of their force. They, along with the pilots of the planes from the "jeep" carriers, who made many dry runs after their torpedoes had been launched, once again demonstrated the importance of mutual support and cooperation, even unto death.

At Okinawa, it was necessary to establish Destroyer Radar Picket Stations in order that our planes might be properly directed to destroy the enemy Kamikaze attacks. These destroyers took a terrific beating and on one station to the northwest of Okinawa, a destroyer was sunk on each of five successive days. The destroyer which took that station on the sixth day knew there was little chance of returning, yet its acknowledgment of the order was a cheerful "Wilco". The captain realized the importance of his duty and he took his station with the same courage his predecessors had shown. Perhaps the story of one young ensign, whose name is unknown, in one of these destroyers might show the spirit with which these lads fought. After a heavy attack on one of the pickets, I heard the Combat Information Center in that picket report—"Have been attacked by 32 enemy planes. All officers killed but me. I am new, but I will do the best I can on the next attack—forgive me for the mistakes I am about to make". The ship was sunk and the young unknown hero went down with it in the next attack, but he added his bit to the traditions of the Navy and his spirit will be followed in the future by other young Americans who will fight for the freedom of their country.

This war was fought by many men who fought in many ways—this war was won because all hands did their best to help. Men in combat would have been helpless without excellent equipment supplied by men and women at home working together with enthusiasm. All hands in the Navy appreciate the leadership of members of the American Society of Naval Engineers in directing the scientific and industrial might of the country into channels which gave the Navy the means with which to fight a successful war.

Wars require a national effort to win and no part of the national combat team can be omitted or neglected—without grave danger of losing. Production of good equipment early enough to be used is as much a function of modern war as combat. Nor can any man determine just who is the most important member of the team. The relative importance of the various components of our national combat team changes from time to time just as the relative importance of the various weapons changes under changing conditions. I have stressed the actions of the surface Navy tonight, but their acts of heroism were duplicated by submariners, by aviators, by the Marines and by our friends, the Army. Let no man doubt the effectiveness or the importance of all components. The swimmer of an under water demolition team, swimming silently into an enemy beach in the dead of night, tackles his dangerous task because he knows its accomplishment will save many lives of the landing force tomorrow. The small PT boat attacking a battleship does so, knowing he is carrying out his part in the plan. It is important that all components of our team do their work well, in order that other component may succeed.

All of these war episodes have now become history. They are important memories—they are lessons to be remembered—they are Naval traditions. It is important, however, that we not fight another war with plans made for this one. We want peace. But we won't have peace if we grow weak and pussillanimous. The United States has duties and obligations. We have the responsibilities of a strong nation, but we cannot fulfill those responsibilities unless we are strong. We can be strong with the continued help of those who turned out superior equipment at record speed during the war—without that help—without that member of our team—we are sunk.

"ENGINEERING HORIZONS."*

By Charles F. Kettering.

Mr. Secretary, Mr. Toastmaster, Members of the Navy and Gentlemen:

I don't know how you would say that any other way. There is always somebody who tries to misinterpret things. Nevertheless, I understand that this great Society is made up of members of the Navy and members of the civilian groups and that they have rated the civilians under three headings: the manufacturers, those people who carry out in a modest degree of sincerity the designs of the Navy; the suppliers, those people who make things that are a joint design of the Navy and the manufacturers; and the vendors, those people who try to sell to the Navy things which they don't want. There may be some other classifications, but that, in the main, I understand are the three major divisions. When the Commodore was talking about the surface ships, when he talked about the marvelous tradition of the Navy, and, in some of those stories, when he said this was carrying out Naval tradition, it was Naval tradition brought up to date with the best that engineering and manufacturing and all of the other factors could bring into it. So, the traditions improve and can be added to, as well as can the mechanisms and the designs, because each new factor that is introduced into the material end of the thing will carry along with it a new factor of tradition, which becomes an improvement, an addition, or a new perspective.

Now, somebody has graciously assigned me the subject of "Engineering Horizons." It seems to me it is a good thing at a time like this when the world is settled back into the perfect routine of peace and calm after a great conflict to take a little stock and see where we are—and from that we can then devise, perhaps, and look forward to the kind of things that an organization like this should do.

In this great war we spent something like six hundred billion dollars. Now, since none of our adding machines carry out that far, we don't understand what that means, but I understand

* One of the principal speeches at the Annual Banquet.

that there are about two billion people in the world. That would mean that we spent $300.00 for every man, woman and child in the world, including the Hottentots. And, speaking of the Hottentots, they have brought about one of the greatest economic discoveries that has ever been made; in fact I do not know but what this discovery in economics is second only to the atomic bomb, because it has been found out very recently that if you are going to supply that quart of milk every day to the Hottentots that you have to have a cow, and that seems to have been a very, very, unexpected discovery. You know when you can do this, they call it *imagineering*—there are several kinds of it—there is that with and without experience—and the difference between experienced *imagineering* and inexperienced *imagineering* is that the experienced fellow has had a customer. We never figure the Navy is a customer, of course, because the Navy is not a thing apart from the rest of us and it is just as much our Navy as it is to these officers. If we don't do our part, well, why they can't do their part well. Therefore, in the Navy today and in that great accomplishment of the last war, we saw every phase of human relationship from elementary education to advanced education, from this, that and the other thing, utilizing every one of the factors which was available in our kind of a country. We prepared for war by execution and by constant use of the things that we knew how to do in peace.

We sometimes misinterpret the word democracy. Democracy politically is a long way of spelling votes, and that's all; but democracy in an enterprising country like our is one in which we have continuous elections every day. The stores up and down the street are the voting booths. The manufacturers that come down here and present their things to the Armed Forces are all engaged in a continuous election, and it depends whether they buy this or that in the store as to whether or not they elect the concern that makes it, even though they don't know who they are; and sometimes I think it is a good thing. These advertisements in the paper—they are political advertisements—they're advertising for you to come and look at their particular thing.

No other country in the world, of anything like our size, stands today in the great economic picture. In fact it is the only one that

is today strong and vigorous after this great conflict. We sometimes say, "Well, we were just fortunate in not having any of our cities destroyed or bombed or all that kind of thing". We want to be sure that we understand what that means, because with an expenditure of six hundred billion dollars (and I believe there is a slight residue debt left over), you'll find out that you could replace Washington, New York, Philadelphia, Chicago and several other points east and west and have enough left over to build a good Navy. We did lose and we want to recognize what we lost, but what did we get for the money we spent? Well, we say we won a victory. We won a marvelous victory. And to the Navy should go all the types of honorable expression of appreciation that can possibly be written. We won a victory which insured to us the kind of a thing that we were before the war, that we could go ahead and do what we wanted to do, we could make and try to sell, we could invent, we could do all of those things; and after the war was over a strange kind of a residue odor came over our country which said that it was impolite for a country to fight and retain the degree of freedom that we had gained. And, therefore, for some reason it became almost disrespectable to be a good manufacturer, a good inventor, a good engineer, etc., because those people did that thing for profit. And what is profit when you get the economist to define it? It is the difference between the sheriff and the ship, I should say. It is the difference between going concerns that can afford to go ahead, advance, bring in new ideas and those which stand still. I've always said that the only difference between a red balance sheet and a black one was that the red are the boo's of the community, and the black is the applause of your customers, because if they didn't like you, and if your product wasn't right, you wouldn't have it black. So we need to think here of a going concern of the greatest nation in the world which has gone through this war and still has the ability to go ahead and reconstruct and to plan and to try to have some new horizons and a recognition that the final line has not yet been written.

So, what are these new engineering horizons? It's perfectly simple if you read magazines to find out that everything that we have is gone—it's antiquated. I presume if I judged from

current magazine articles whose authors I haven't questioned that this will be the last report on surface ships that will ever be made. I presume that submarines are gone, and therefore this appropriation which we seem to feel the Navy needs to continue its active thinking is after all only unnecessary "made work", so to speak, until the magicians can pull all this stuff out of the hat. I have been in this engineering game long enough to know that these developments are scattered along the great highway of time in rather small bits, and they don't come in great chunks so that all of a sudden you can unload the wagons with what you have and put on the new loads and go ahead. And, of course, my idea of the horizons of engineering is that we shall continue to do the best we can with everything we have and, in addition, have an open mind to the new things that are coming in.

Any new thing that comes in, always comes in with a prejudice. I happen to have known the history of the aircraft business from the time it started because the Wrights were from Dayton and I knew the Wright brothers when they were my neighbors. Of course you all remember the classical story as to why they went to Kittyhawk—which brings in the very important subject of statistics. They wrote to the Post Office Department to find out where they could go where they might have an average wind of 30 miles an hour. The Post Office Department, I believe, was the Weather Department at that time, and after several weeks delay this Department told them at Kittyhawk. And so that is the reason they went there. The Wrights said the figures were absolutely right—it blew 60 miles one day and was calm the next. Of course, it had been definitely demonstrated that a heavier than air machine couldn't fly, so when they made that successful flight down there along in the middle of December they flew four or five times in one day. It is interesting to note that their first flight was quite a little bit less than the wing span of our largest airplanes today. So they wired home to their sister and said "We've been very successful with our power flights, we're very happy and we are going to be home for Christmas". So when the sister got the telegram, she thought that would certainly be a great news item; she called the newspapers in Dayton and the boys were playing pinochle and the telephone rang and rang and finally the

fellow took up the phone and said "Yes". She said "This is Katherine Wright", and she read the telegram. "We have made our successful flight with power, we are both very happy and we'll be home for Christmas". The fellow said "Thanks so much for calling us up, I'm glad to know the boys are going to get home". I'm telling you this because it had been proven in various ways that heavier than air machines couldn't fly despite the fact that before the windows in which those calculators might have been working there were birds flying, but you must understand that birds were dumb animals. Sometimes we can become too intelligent to interpret such elementary things as that. So, if we want to have some new engineering horizons, we need to look at some of the things that nature has done. Nature has been pretty clever. We don't know how we raise and lower our arms because we have a motor here, a muscle motor, about which nobody has the slighest idea of how it works—and you have found out if you read anything about this physiology and medicine that if you don't understand a thing you just give it a Latin or Greek name. For instance, we have been working for years on a little subject called chlorophyl. Chlorophyl is Greek for green leaf. Hell, we don't know any more about it in Greek than we do about it in English. And then we get into these grooves sometimes because this is the easiest thing to do and also because we don't have to expose the fact that we don't know. And after we do those things pretty long then they become the established line. I have a little story that's an extremely good illustration of that—My home is in Dayton, I can't get a job there so I have to work in Detroit. And I have driven back and forth many, many years—in fact 35 or 40 years—so I know all the roads. It used to take us two days to make that trip, and now the roads have gotten better. So one of my associates who has worked with me for a great many years said to me one day "I understand you drive from Dayton to Detroit in four hours and a half—or four hours and fifteen minutes". I said "Yes, I do". He said "I don't believe it". He said "I know I am a damn sight better driver than you are and I can't do it in that length of time". "Well," I said, "Why don't you go along down with me Friday?" So we went down and we slid into Dayton in four hours and fifteen minutes. He said "Hell, no wonder you

can do it in four hours and fifteen minutes, you don't stay on Route 25".

It is the purpose of research and engineering to survey the territory on the sides of the roads. There is one thing about nature—she has never subdivided her responsibilities. If she is going to make a tree she doesn't call in an engineer, a biologist, a physiologist, etc.; if she did, as you perhaps know, you wouldn't have any trees because you'd never get any agreement. Admiral King and I were just talking about that article which appeared in a recent number of your JOURNAL here, in which the fellow analyzed the efficiencies of committees. I believe he arrived at the conclusion that the best committee in the world would be one and a half men. I read the article and it is a very, very learned treatise. A minor discussion I think is permissible at this time as to why the half man got in there. He's to take the responsibility, in case the whole man is wrong. But, nevertheless, when we see the accomplishment of the Navy, when we see what was done and all the various kinds of ships and equipment that were produced, it covers the whole list. When we see these billions of dollars that were spent in equipment and ships and all that kind of stuff for the Navy (that is before taxes and renegotiation, of course, and I don't think there were any Government surpluses at that time either), when we see what we are able to do in a country that was purely an industrial country, then I think we see the significance of having a strong fundamental Navy that can know and plan what needs to be done.

This gang of manufacturers, suppliers and vendors or whatever we are here, Mr. Secretary, can make any damn thing that you fellows want, if you'll give us a couple of days notice. So you can pitch your ideas just as high as you care to—you can imagine the things that you'd like to do—you can imagine what a Navy would be if it were all things that all the theoretical people can compile. If you'll let us have a few days, we can get you something that will make it difficult for them at least.

The Japanese had their plans well laid—they knew we were a rubber tired industry and they knew that we would have a very difficult time getting along if we didn't have rubber. And they did the most strategic thing in the world when they cut our rubber

supply off. But they overlooked the fact that we had made 50 or 100 tons of what everybody said was a very poor grade of synthetic rubber before, but that had given us a little practice, a little idea of what could be done. And that synthetic rubber program was one of the most important technical things that was ever done. There was a great deal of fuss, of course, as to whether it ought to be made out of oil, or whether it ought to be made out of alcohol, but there wasn't any real fundamental technical reasons back of that, there were just more farmers that could vote than there were refiners. But, nevertheless, we got a fine lot of synthetic rubber and we went along about our business. But if we hadn't had that little, if you hadn't had your Naval research laboratories, if you hadn't been trying radar, if you hadn't been trying this, if you hadn't had a sample, no matter how incomplete it was, you couldn't have done what we did. So, if we are to write the picture of the horizons of the future for engineering and for the Navy and for research and for everything else, let's look as far as we can, let's think, let's argue, let's talk—and let's fight to get enough appropriations that these men can have those elementary samples, so that we can have everything that might be necessary to a more intelligent population than we have.

This country contains six per cent of the population of the world. It has 60% or 70% of this and 70% of that. We have 21 telephones per hundred population—they're not available at the present time, but we still have them. There is a great country with which we are having some slight argument today that has eight-tenths of one telephone per hundred and they're not allowed to use that one either. We have these things which no country in the world ever had. If I were a young man, I'd try to be a salesman, I'd try to go out and sell back to this great community of one hundred forty million people, the greatest organization of engineers, of people, of schools and everything else that the world has ever seen, under the name of the United States of America.

Society Lapel Button.

Shown on page 284 is an illustration of the lapel button of the Society. It is believed that it will be conceded that this is a very fine, dignified insignia. It is one-half inch in diameter.

The oak leaves and lettering are red on a gold back-ground. It is available to all members at fifty cents (50c) each.

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